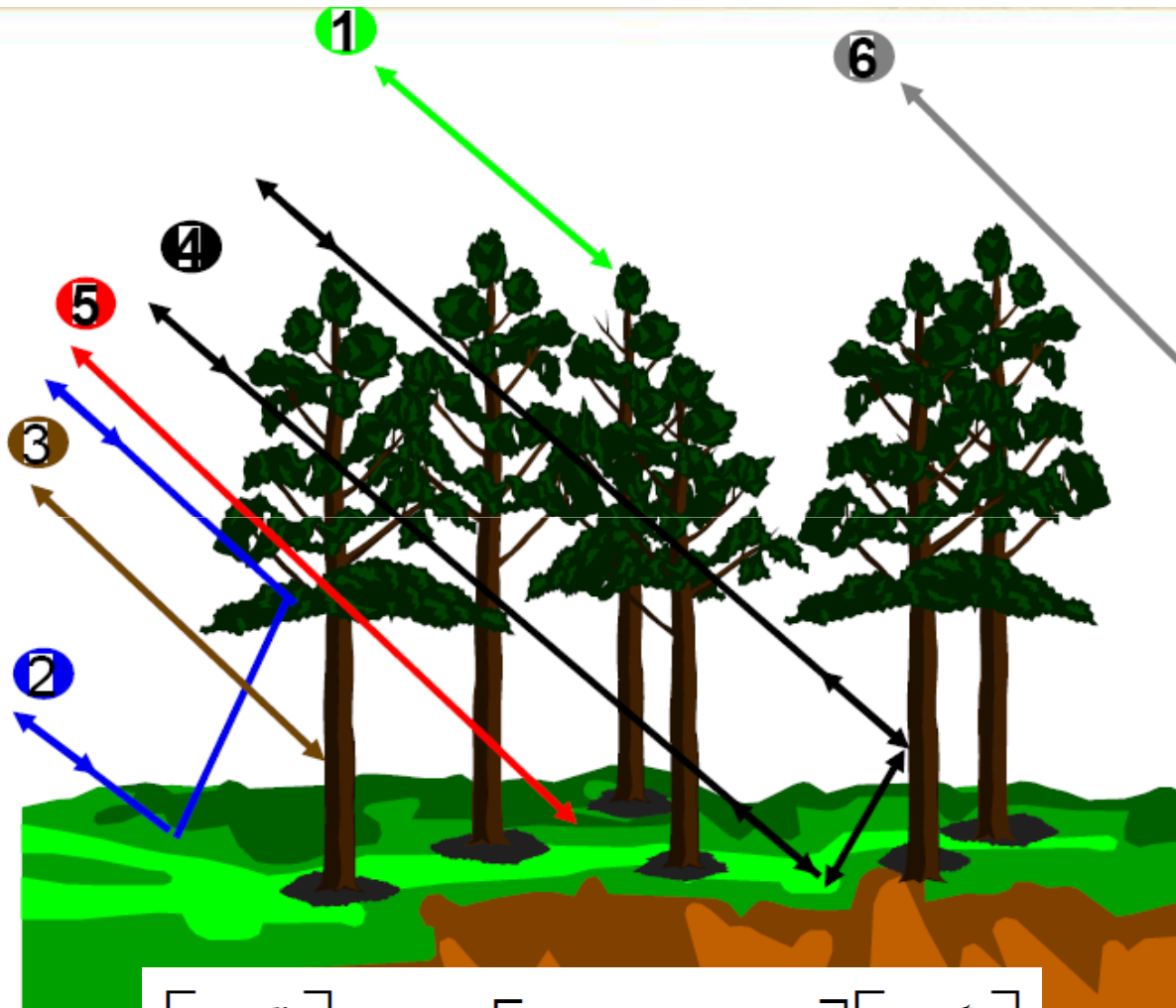


Polarimetrija



Mobitel d.d.,
izobraževanje

4. 9. 2009,
predavanje 20

Prof. dr. Jožko
Budin

$$\begin{bmatrix} E_x^r \\ E_y^r \end{bmatrix} = K \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_x^t \\ E_y^t \end{bmatrix}$$

Polarimetrija

Polarizacija je informacija

- V **radiokomunikacijah** izbiramo polarizacijo glede na karakteristike komunikacijskega kanala. Z njo lahko izboljšamo sprejem in zmanjšamo motnje (primer raznolikost)
- V **radarski polarimetriji** uporabljamo polarizacijo za odkrivanje in prenos dodatne informacije, kot so na primer različne bio-fizikalne karakteristike tal in vegetacije.

Načini daljinskega zaznavanja

1. Pasivno daljinsko zaznavanje – radiometrija

- usmerjen sprejem termičnega sevanja okolja
(termična emisivnost terena, svetlostna temperatura)

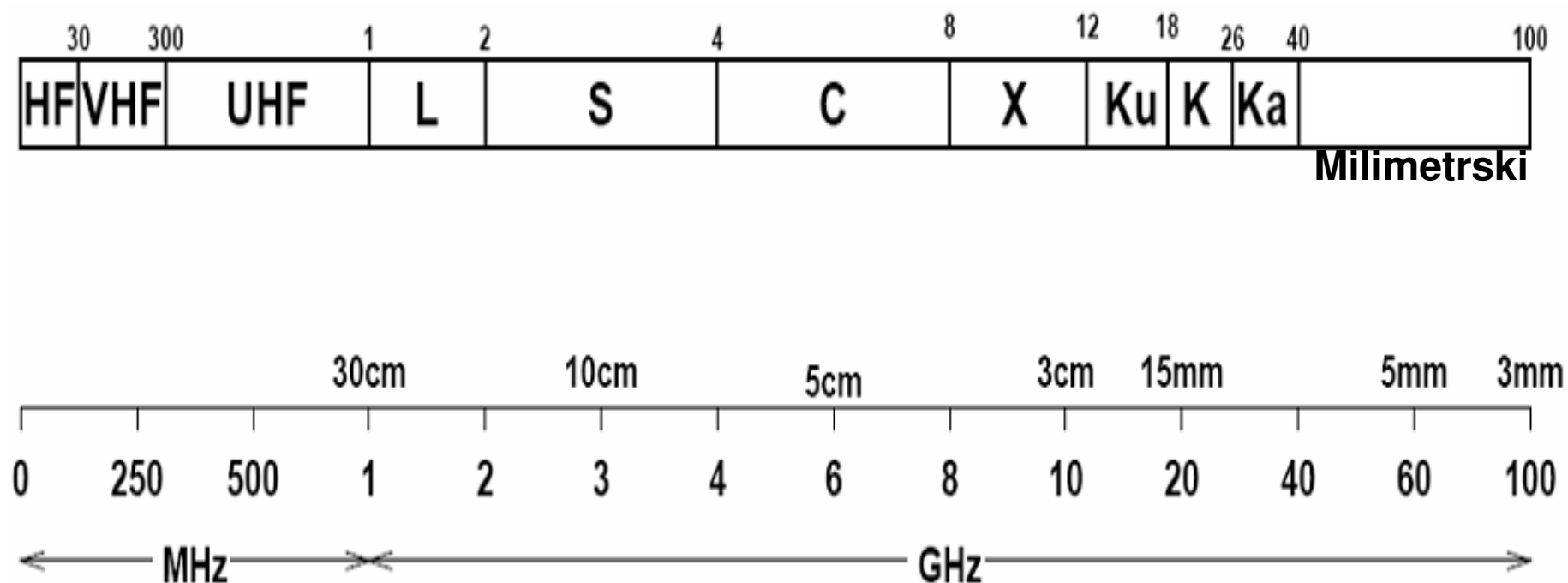
2. Aktivno daljinsko zaznavanje – radarska tehnika

- usmerjena oddaja in sprejem lastnega signala (radar, lidar, sonar)
- radar s sintetično odprtino

3. Polarimetrično zaznavanje - različna polarizacija

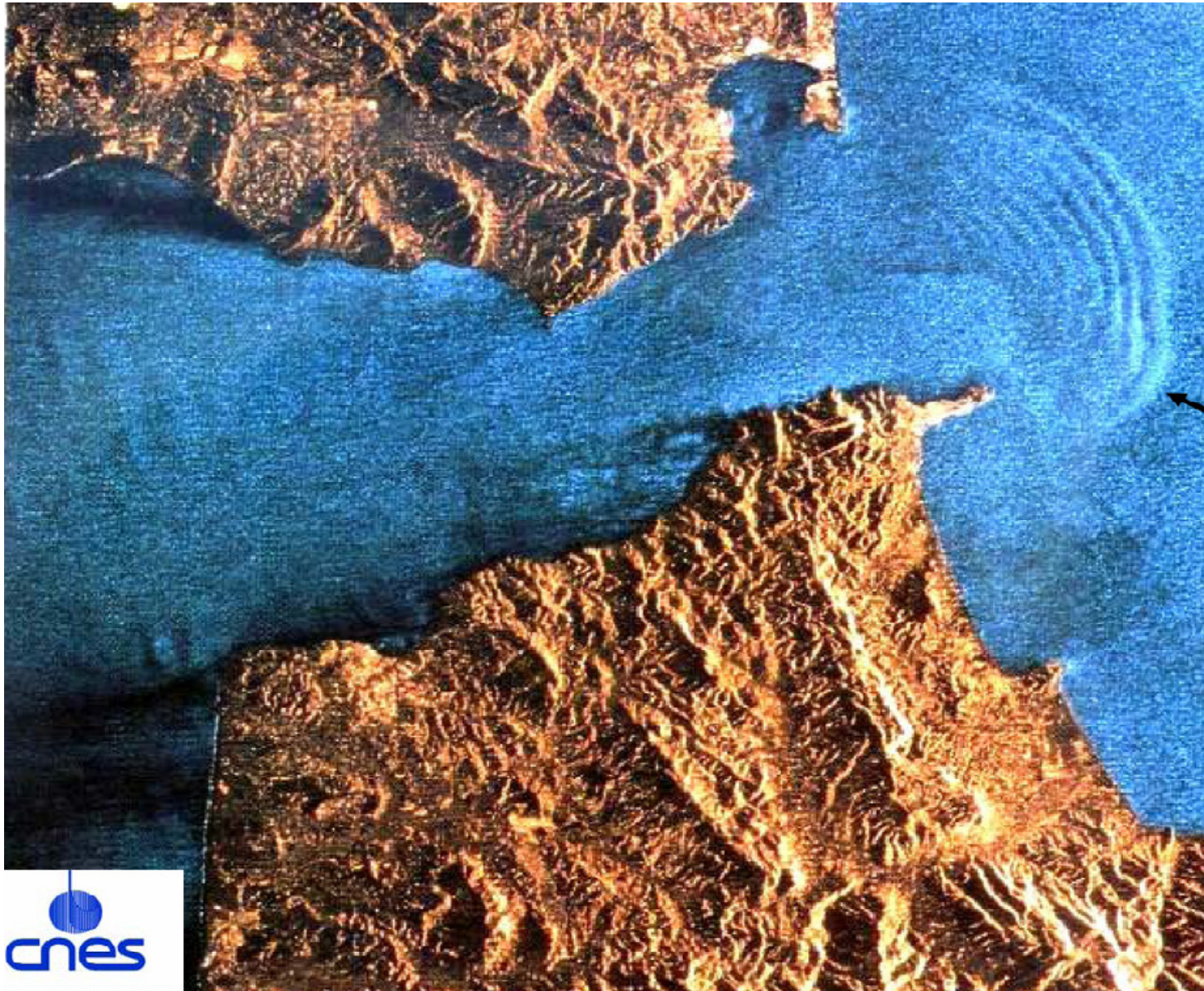
- VV (vertikalna pri oddaji, vertikalna pri sprejemu), ali
- HH, HV, VH

Frekvenčni pasovi



SAR – posnetek Gibraltarja

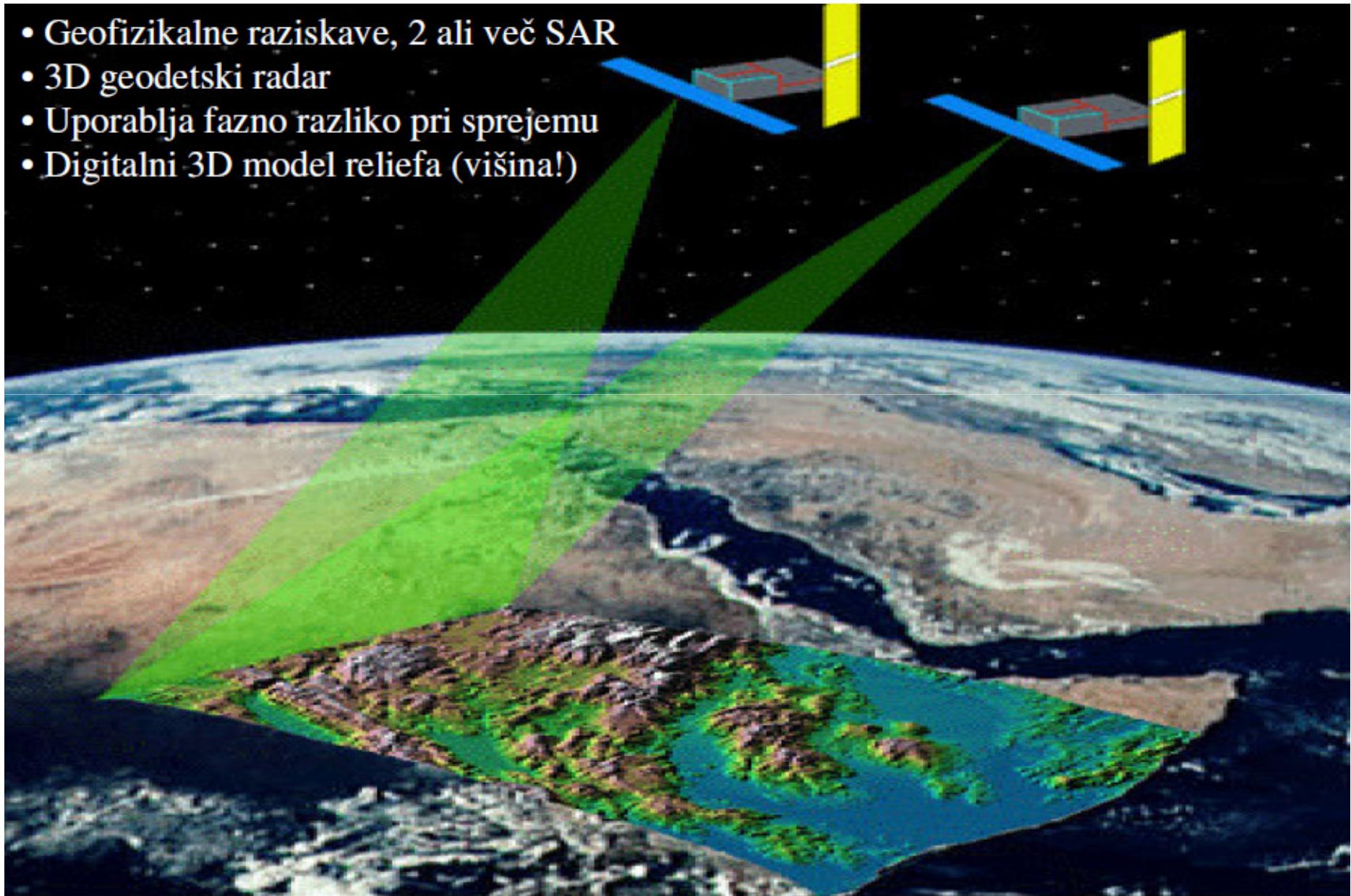
5



Dvosatelitski enopreletni InSAR

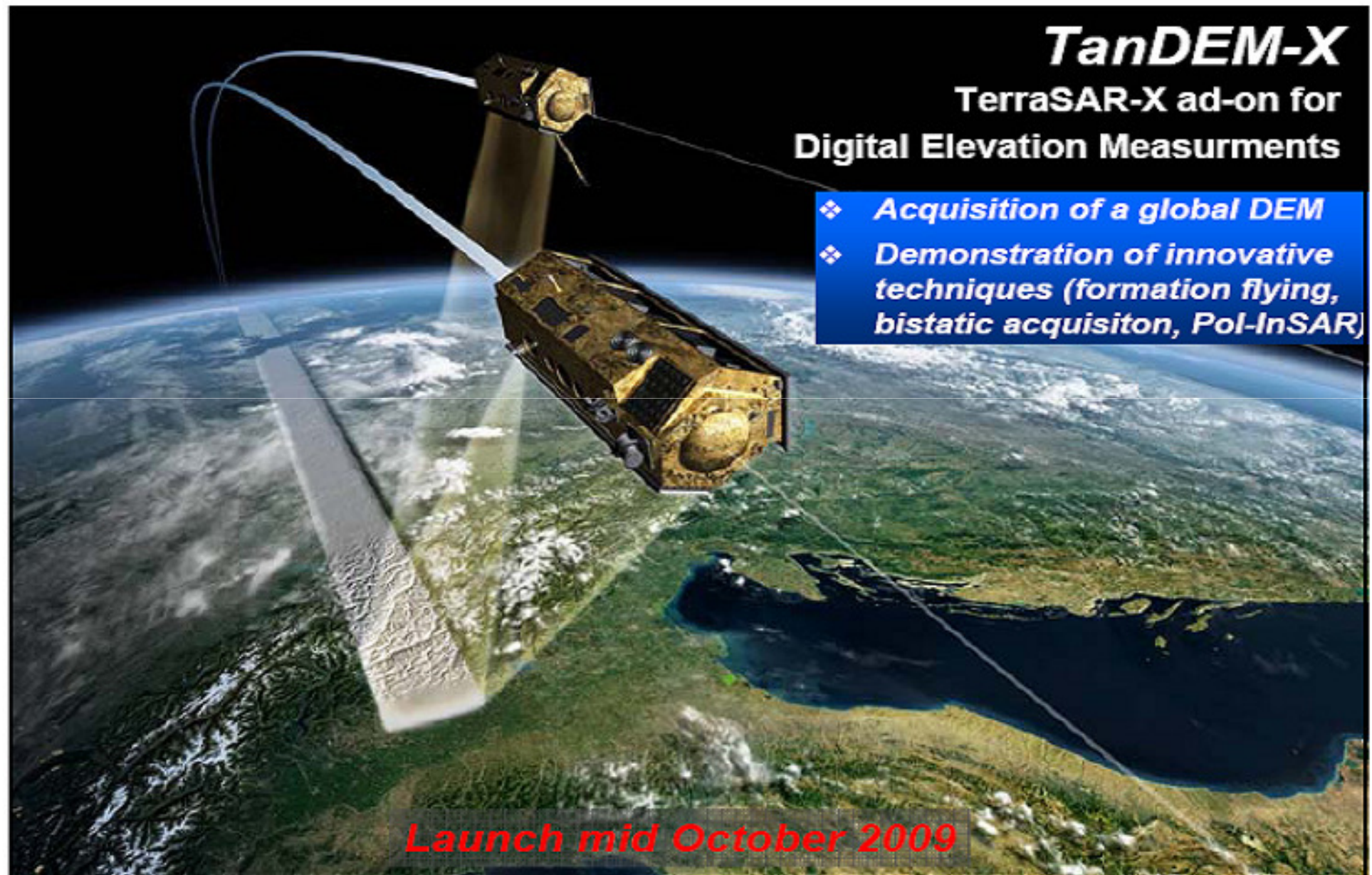
6

- Geofizikalne raziskave, 2 ali več SAR
- 3D geodetski radar
- Uporablja fazno razliko pri sprejemu
- Digitalni 3D model reliefa (višina!)



TanDEM-X

7



TanDEM-X
TerraSAR-X ad-on for
Digital Elevation Measurements

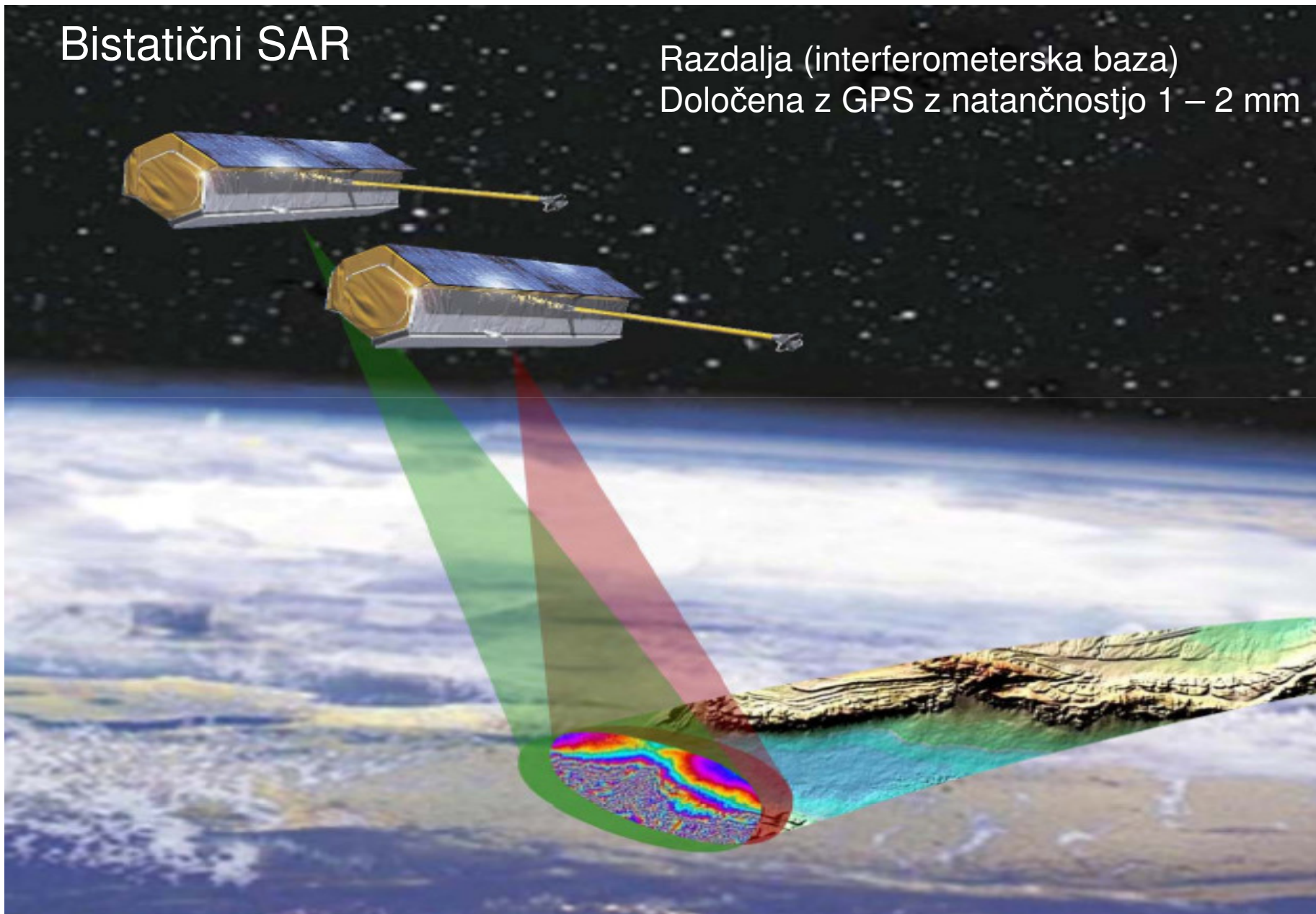
- ❖ *Acquisition of a global DEM*
- ❖ *Demonstration of innovative techniques (formation flying, bistatic acquisition, Pol-InSAR)*

Launch mid October 2009

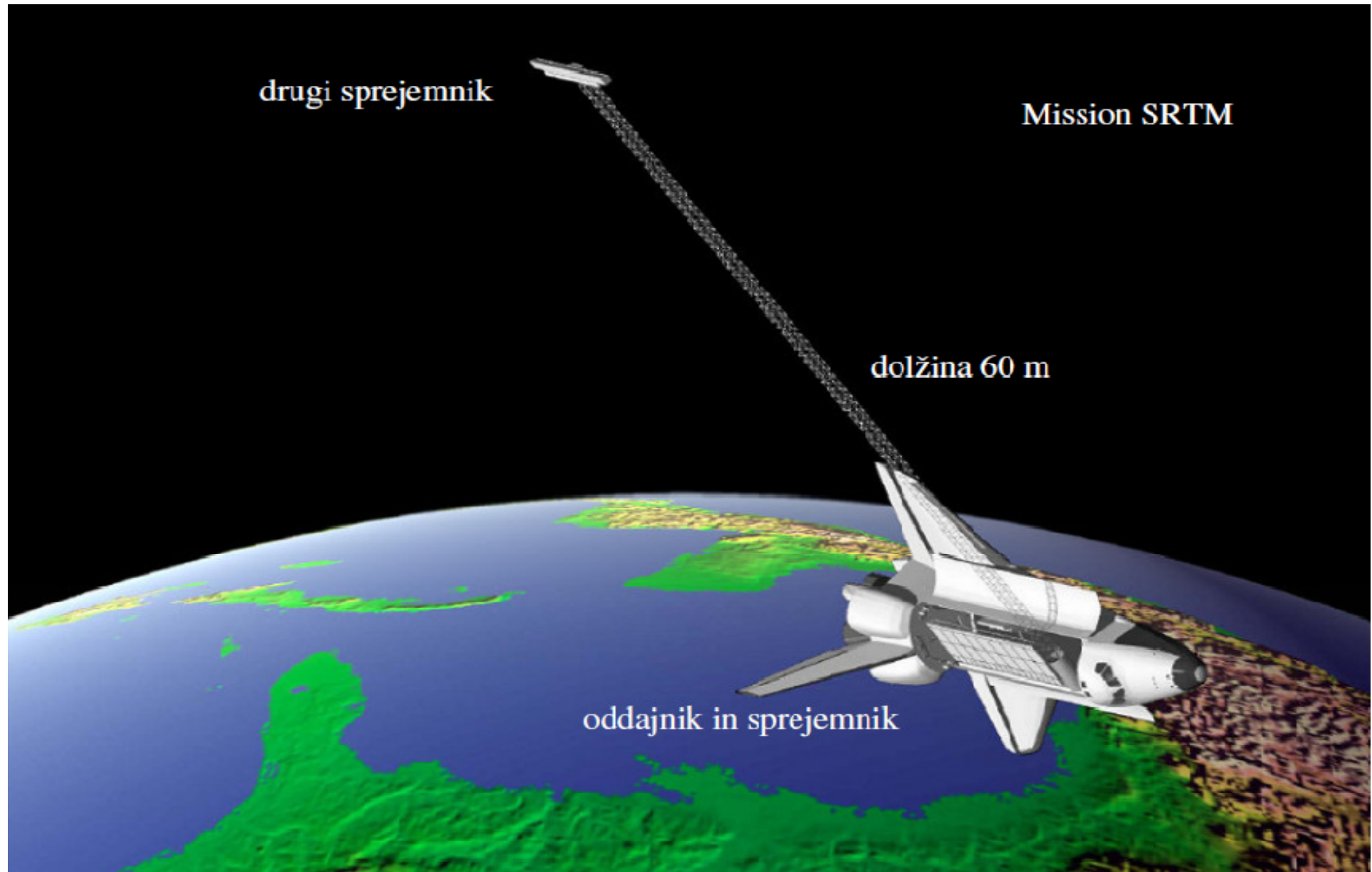
TanDEM – X (2009)

Bistatični SAR

Razdalja (interferometerska baza)
Določena z GPS z natančnostjo 1 – 2 mm



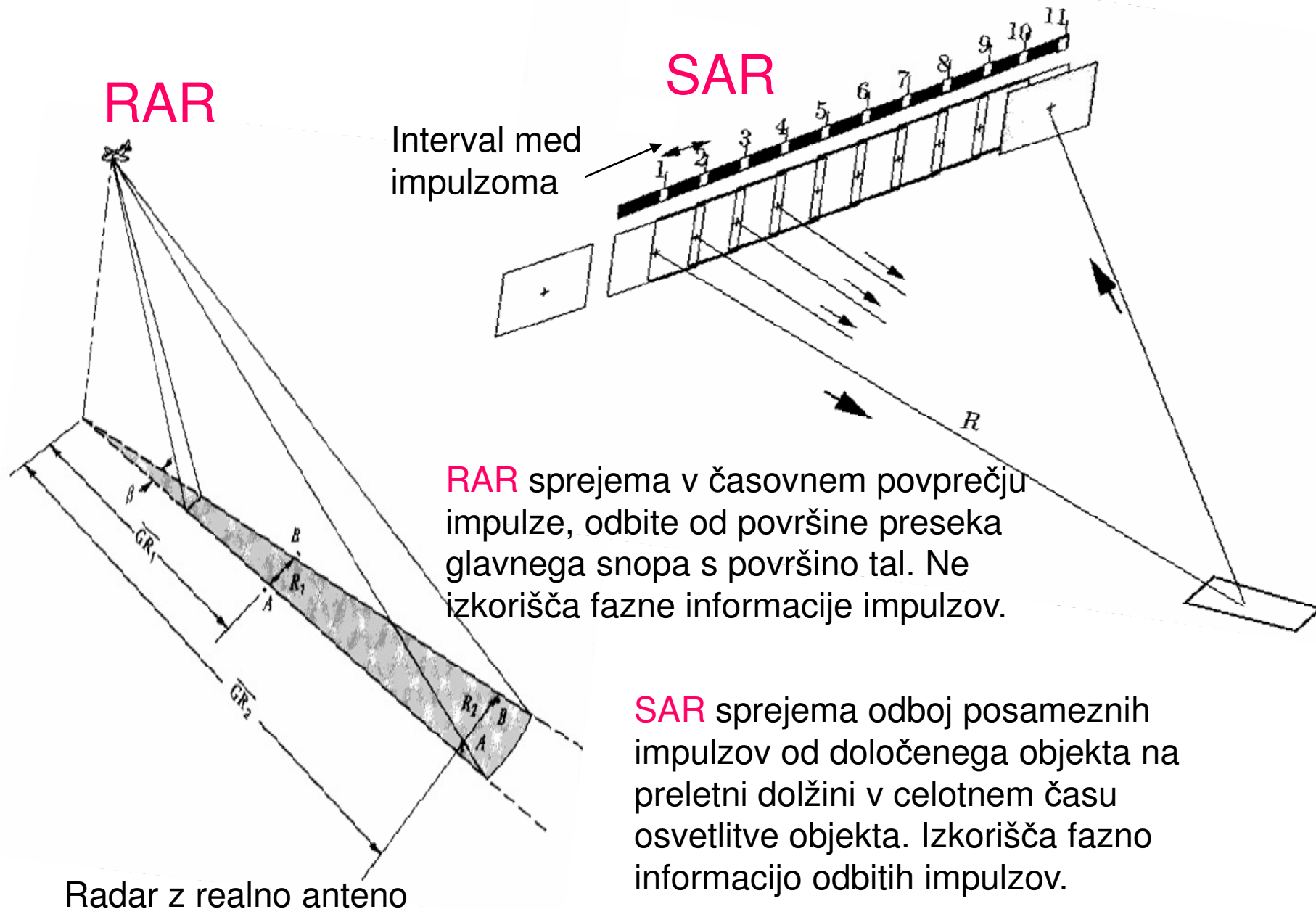
InSAR na raketoplanu



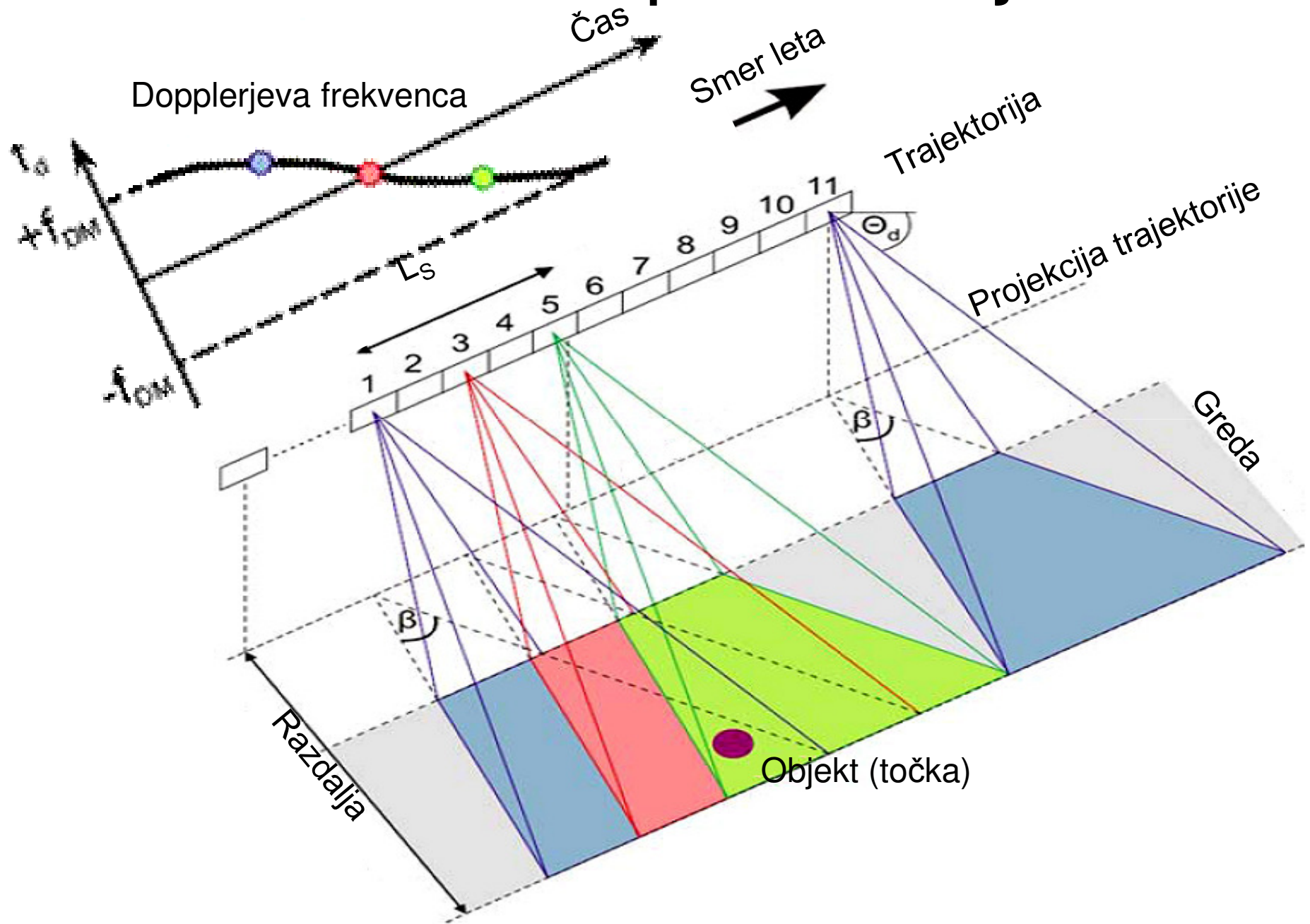
RAR - SAR

1. RAR (Real Aperture Radar) – Radar s stvarno anteno, običajni radar
 - Resolucija po kotu je odvisna od velikosti antene L/λ , kjer je L dolžina antene
2. SAR (Synthetic Aperture Radar) – Radar s sintetično odprtino
 - Visoko resolucijo dosega radar s sintetično anteno, ki ima preletno (sintetično) dolžino $L_s \gg L$ letala ali satelita.
 - Resolucija po azimutu je $d/2$, kjer je d velikost (majhne) antene na letalu ali satelitu.

RAR in SAR

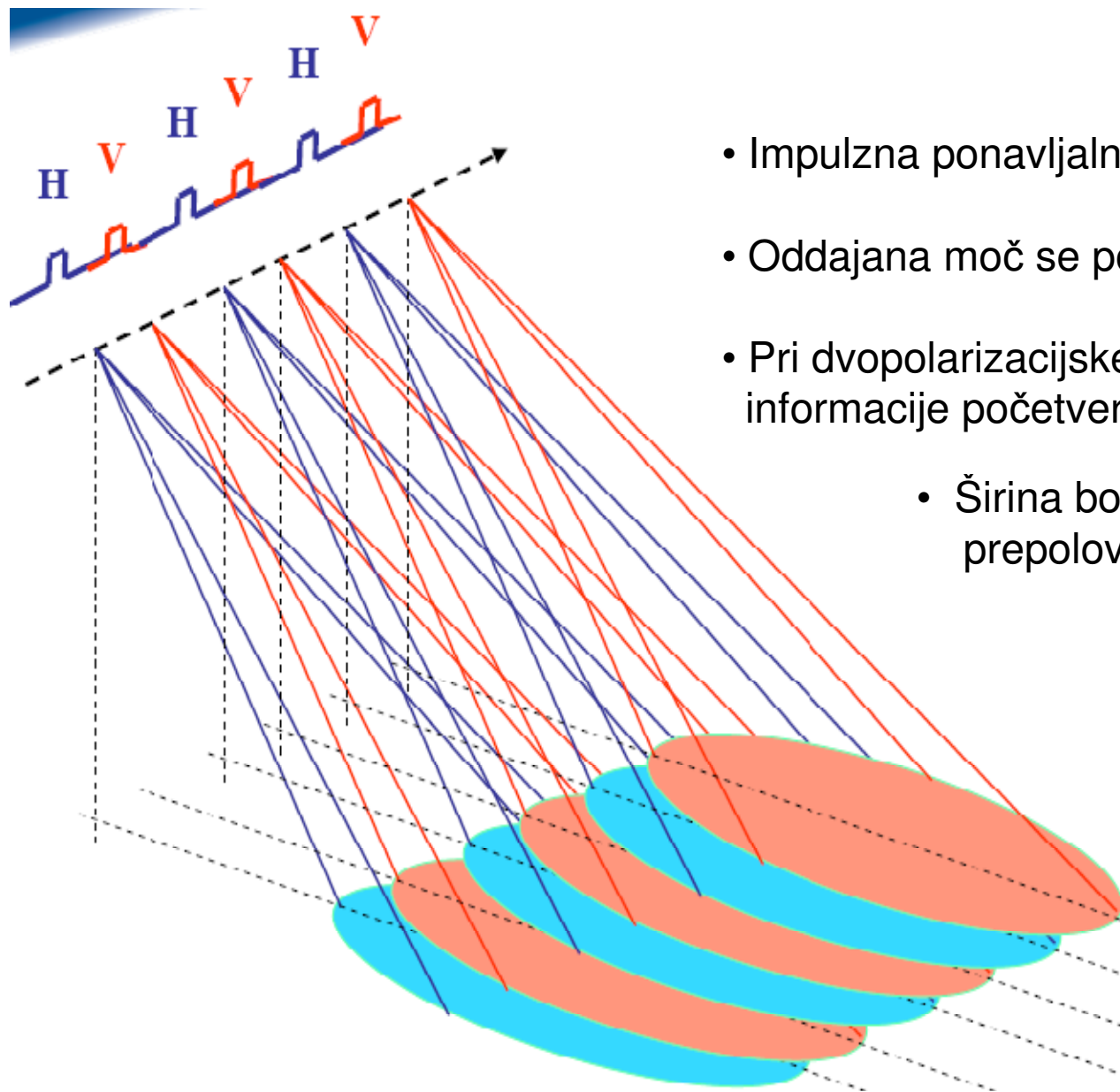


SAR - enopolarizacijski



PoISAR - dvopolarizacijski

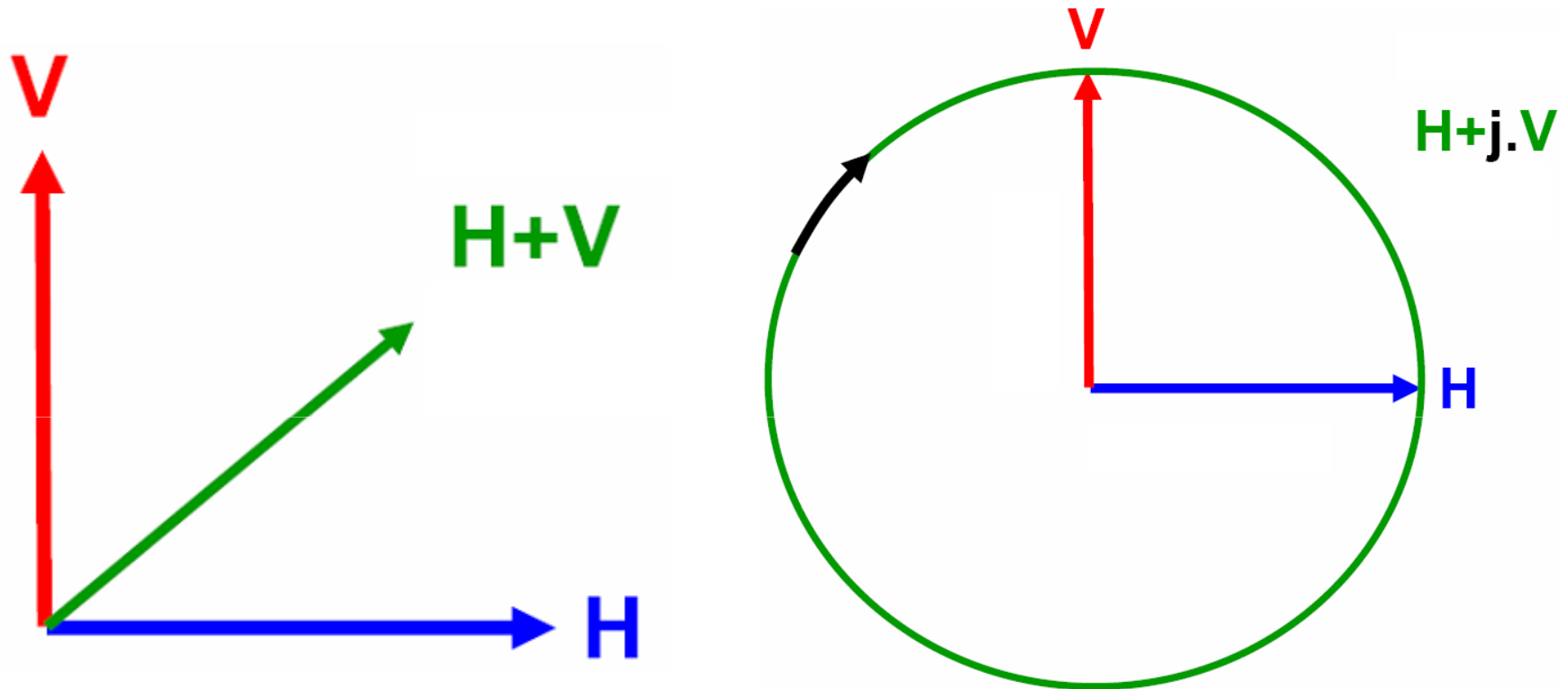
13



- Impulzna ponavljalna frekvenca se podvoji
- Oddajana moč se podvoji
- Pri dvopolarizacijskem sprejemu se količina informacije početrubi.
- Širina bočnega pasu se prepolovi.

Linearna in krožna polarizacija

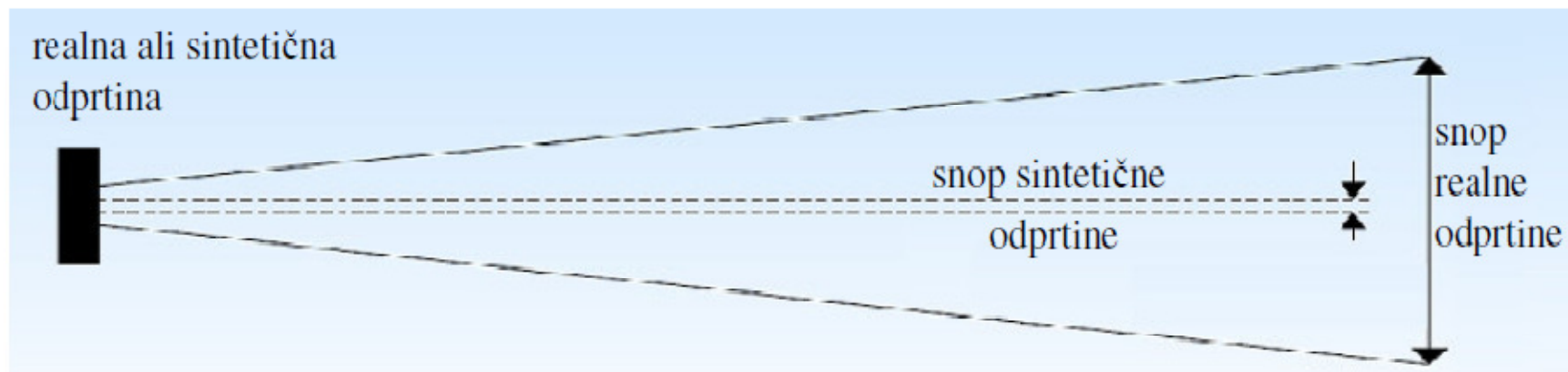
14



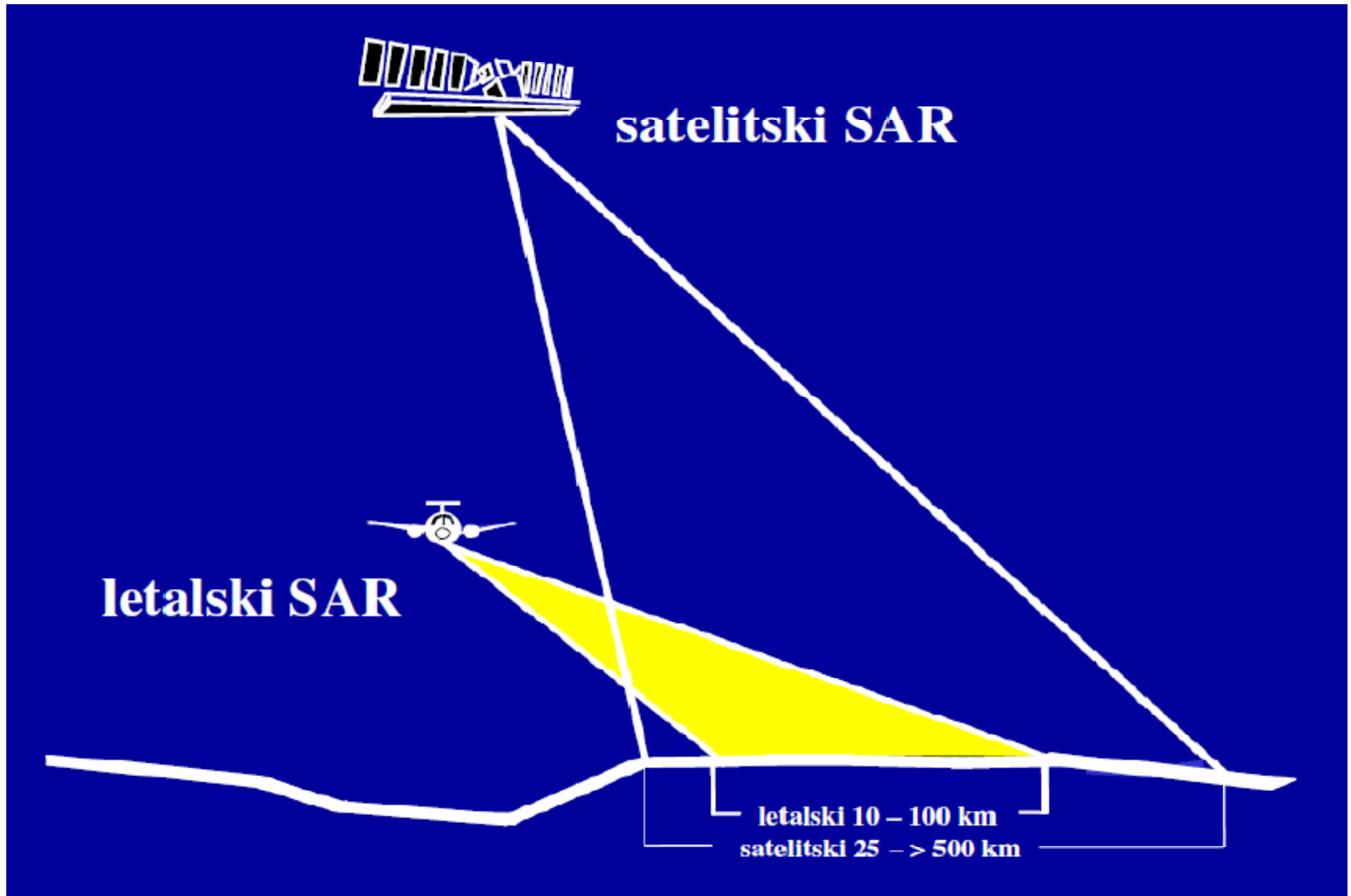
Pol-InSAR sistemi uporabljajo linearno polarizacijo.

Realna in sintetična odprtina

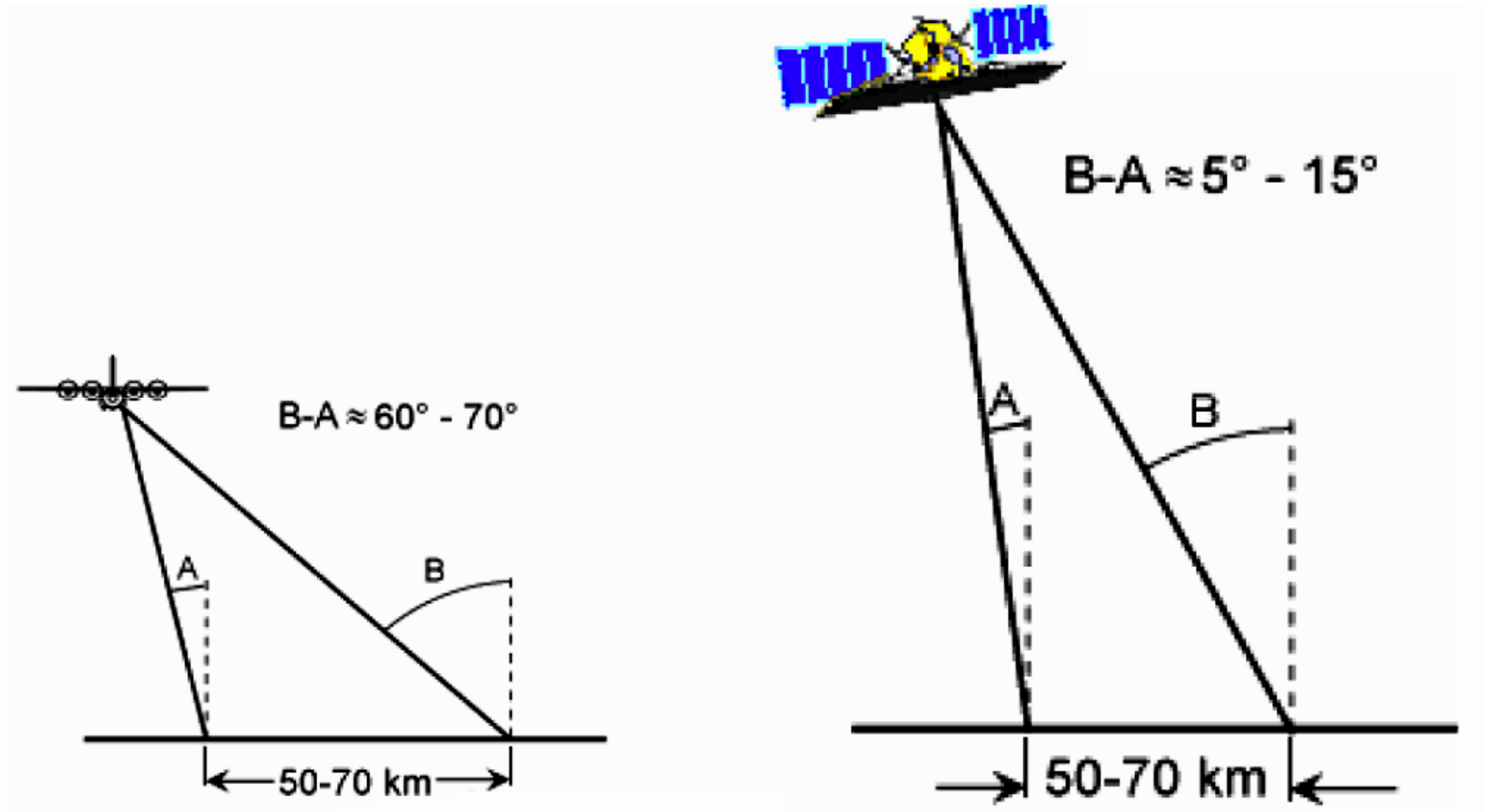
- Realna antena (Real Aperture Radar - RAR)
- Sintetična (sintezna) antena (Syntetic Aperture Radar – SAR)
- Interferometrični radar (Interferometric SAR – InSAR)
- Diferencialni interferometrični radar D-InSAR
- Mnogopolarizacijski/mnogofrekvenčni InSAR



Satelitski in letalski SAR



Letalski in satelitski SAR



Poševna geometrija

Navpična geometrija

Vrste SAR

SAR Interferometry

Differential SAR interferometry

SAR Polarimetry

Polarimetric SAR Interferometry

SAR Tomography/Multibaseline

Multitemporal SAR

Multifrequency SAR

SAR – radar s sintetično odprtino

1. SAR

- Amplituda, Intenziteta.....kartografski radar

2. InSAR, interferometrični

- Faza.....višina reliefa tal(DMR-DEM)

3. Diferenčni interfer. SAR

- Faza.....spremembe na površini

4. Pol-SAR, polarimetrični SAR

- Polarizacija.....biofizikal. lastnosti površine

5. Pol-InSAR.....lastnosti reliefa, pokrova

6. Mnogovalovni SAR

7. Bistatični SAR

8. Tomografski SAR Pol-Tomo-SAR

9. Holografski SAR Pol-Holo-SAR

10. Geostacionarni SAR ?

Polarimetrični sistemi 1/2

1. SAR – (Synthetic Aperture Radar), radar s sintetično odprtino
 - amplitudna informacija, prikazuje površino tal v pasu bočno (ali dvobočno) glede na let
2. InSAR – Interferenčni SAR
 - fazna informacija, prikazuje višinski relief površine z določeno resolucijo
3. PolSAR – polarizacijski SAR,
 - polarizacijska informacija tal, prikazuje karakteristike površine tal (vrsta, oblika, orientacija, simetrija, entropija objektov, npr. rastja)
4. Pol-InSAR – polarizacijski in interferenčni SAR,
 - fazna in polarizacijska informacija, prikazuje višinski relief in karakteristike površine reliefa.
5. Diferenčni SAR – primerjava prvotne in ponovljene meritve.

Radarska polarimetrija

- Sistemi: SAR, InSAR, PolSAR, Pol-InSAR
- Radarsko opazovanje na različnih oddajnih in sprejemnih polarizacijah; meritev polarizacijske matrike sipanja
- Dodatna informacija za klasifikacijo tal, merjenje bio-fizikalnih lastnosti tal, ocenjevanje biomase
- Radar oddaja signale H in V oz. oddaja izmenoma H na lihih in V na sodih impulzih
- Radar sprejema istočasno H in V na vsakem impulzu
- Skupaj 4 merilni kanali: HH in HV, VH in VV
- Operativni sistemi:
 - Radarsat-2, pas C, 2007, HH, VV, HV, VH
 - ENVISAT, pas C, 2001
 - SIVAM, pas L, 2000
 - TerraSAR-X, 2006, resolucija 1-3 m na 10 km x10 km

Vsestranska uporaba polarimetrije

(angleška terminologija)

22

- ◆ Cartography – DEM, DTM
- ◆ Geology – Geological Mapping
- ◆ Seismology – Co-seismic displacement field
- ◆ Volcanology – Prediction of volcano eruption
- ◆ Forestry – Forest classification, deforest monitoring
- ◆ Soil Science – Soil moisture
- ◆ Glaciology – Glacier motion
- ◆ Oceanography – Ocean wave, wind, circulation, bathymetry
- ◆ Agriculture – Crop monitoring
- ◆ Hydrology – Wetland assessment
- ◆ Environment – Oil spill, hazard monitoring
- ◆ Archaeology – Sub-surface mapping

Osnove radarja bočnega obzora

Resolucija po razdalji:

$$X_r = \frac{c \tau}{2 \sin \theta} = \frac{c}{2 BW \sin \theta}$$

Resolucija po azimutu:

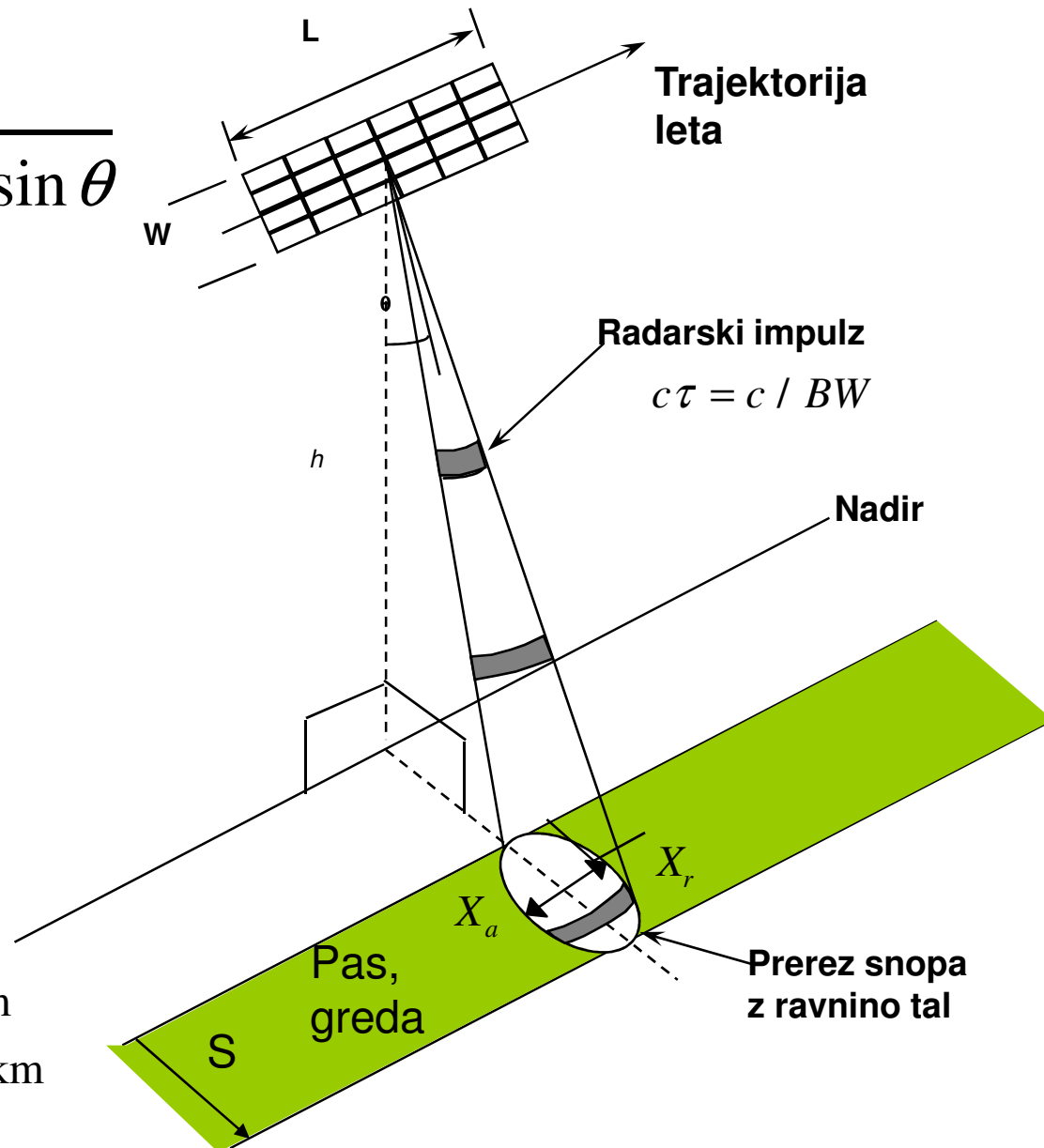
$$X_a = \frac{h \lambda}{L \cos \theta}$$

Širina pasu:

$$S = \frac{h \lambda}{W \cos^2 \theta}$$

Primer:

$$\left. \begin{array}{l} h = 800 \text{ km} \\ \lambda = 24 \text{ cm} \\ BW = 20 \text{ MHz} \\ \theta = 35^\circ \end{array} \right\} \Rightarrow \begin{array}{l} X_r = 13 \text{ m} \\ X_a = 20.5 \text{ km} \end{array}$$



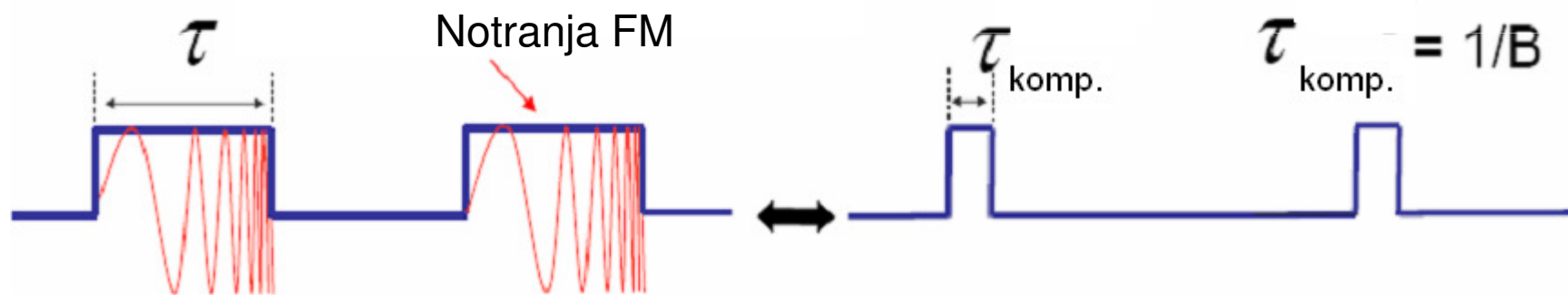
Razločljivost po razdalji

Kompresija signala:

Notranja frekvenčna modulacija v času trajanja τ radarskega impulza. Modulacijski spekter ima povečano širino $B \gg 1/\tau$. Učinek je enak, kot če bi impulz komprimirali na širino

$$\tau_{\text{komp}} \ll \tau$$

FM impulz je na sprejemni strani mogoče B -krat stisniti; s tem se razločljivost po razdalji poveča v razmerju τ/τ_{komp}

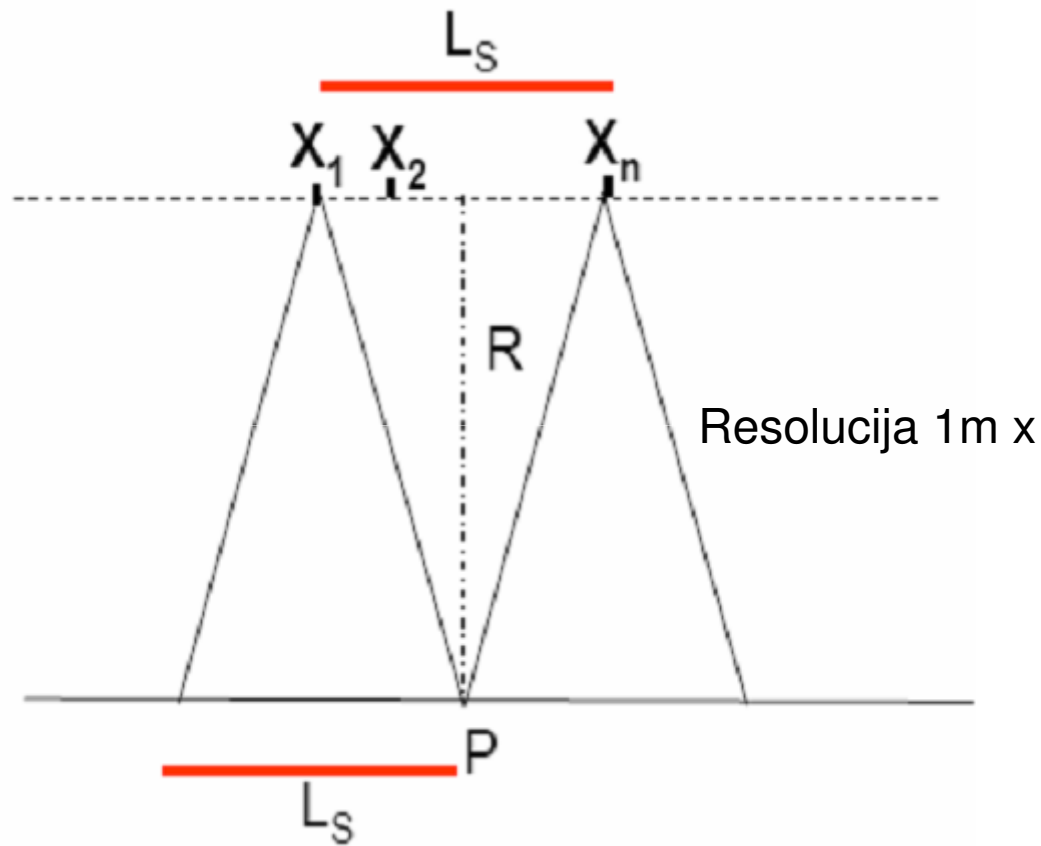


$$\frac{c\tau}{2} \Rightarrow \frac{c}{2B}$$

$$5 \text{ km} \rightarrow 10 \text{ m} \quad (\text{for } B=15 \text{ MHz})$$

Povečanje resolucije zaradi razširjenega spektra

SAR - razločljivost po kotu



$$\text{Resolucija} = \frac{L}{2}$$

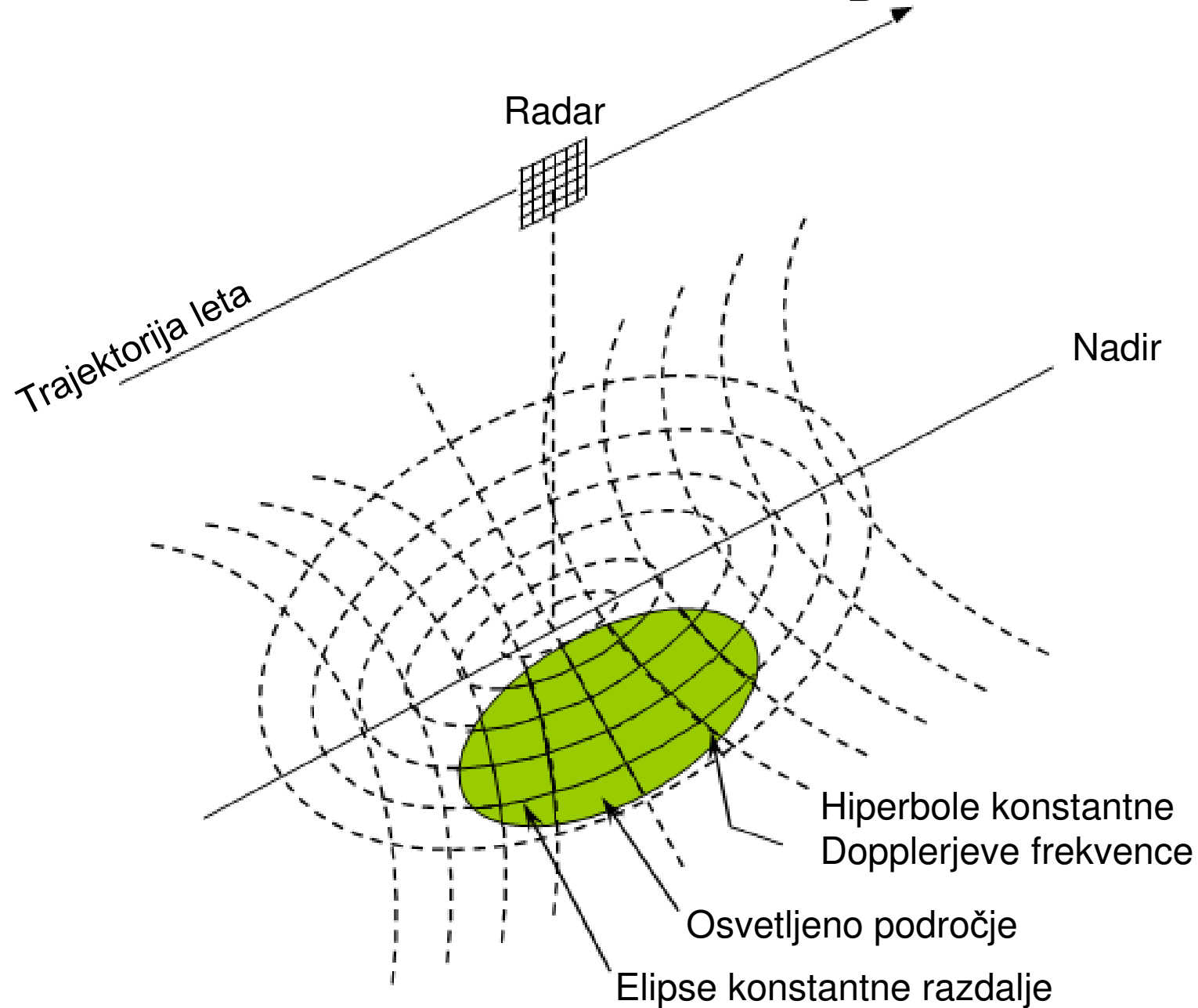
ali

$$\text{Resolucija} = \frac{\lambda R}{L_s}$$

L Fizična dolžina antene

L_s Sintetična preletna dolžina
antene

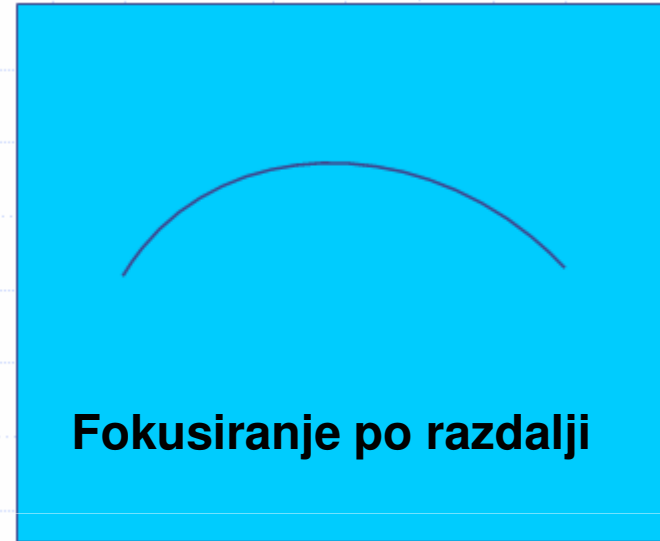
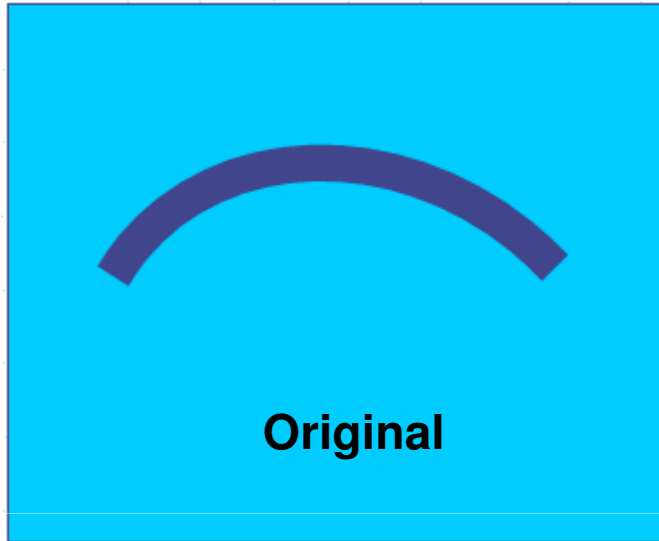
Krivulje $R = \text{konst.}$ in $f_D = \text{konst.}$



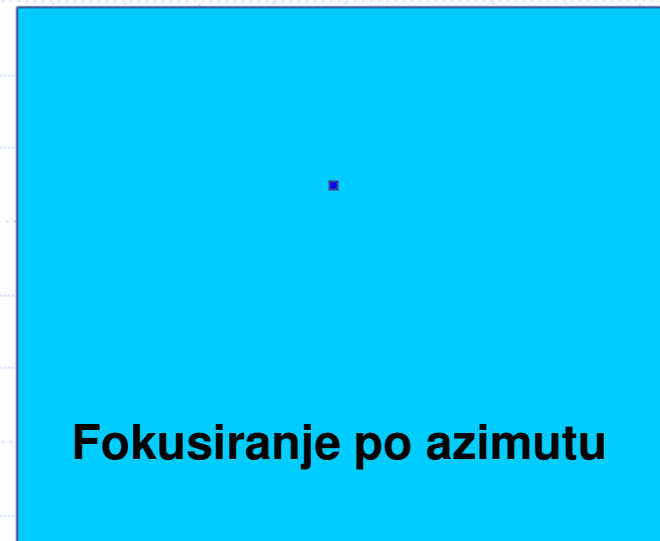
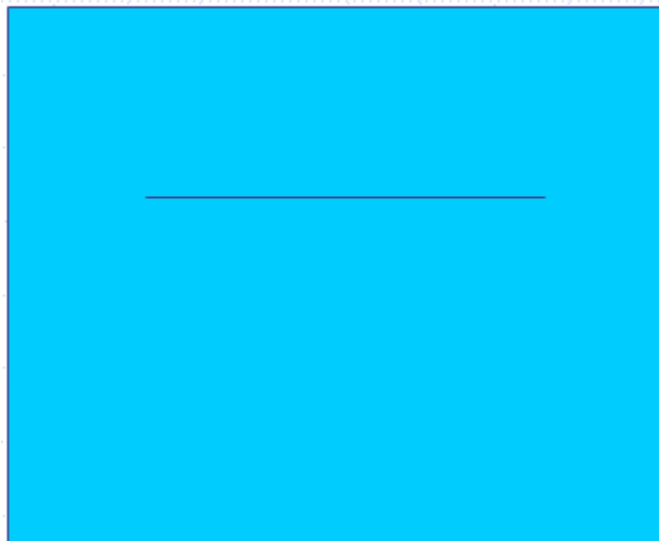
Fokusiranje točkavnega objekta

27

Azimut



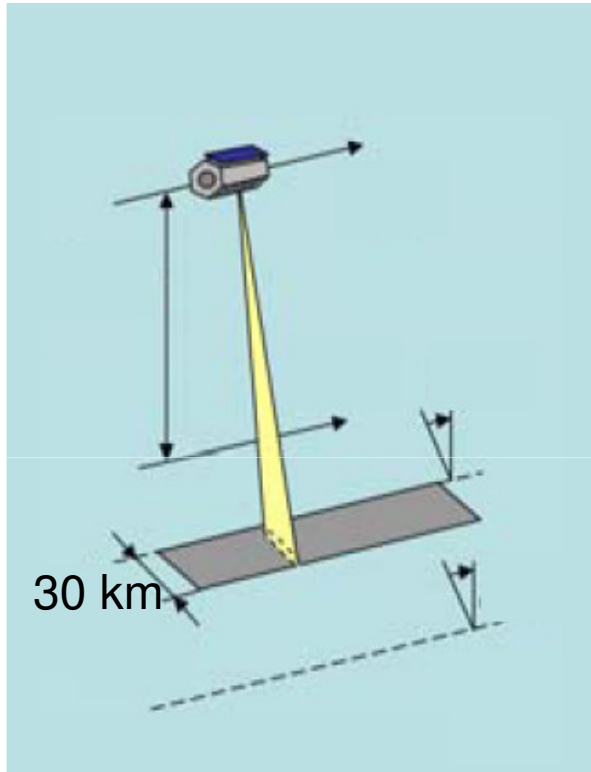
Razdalja



Načini delovanja satelitskega SAR

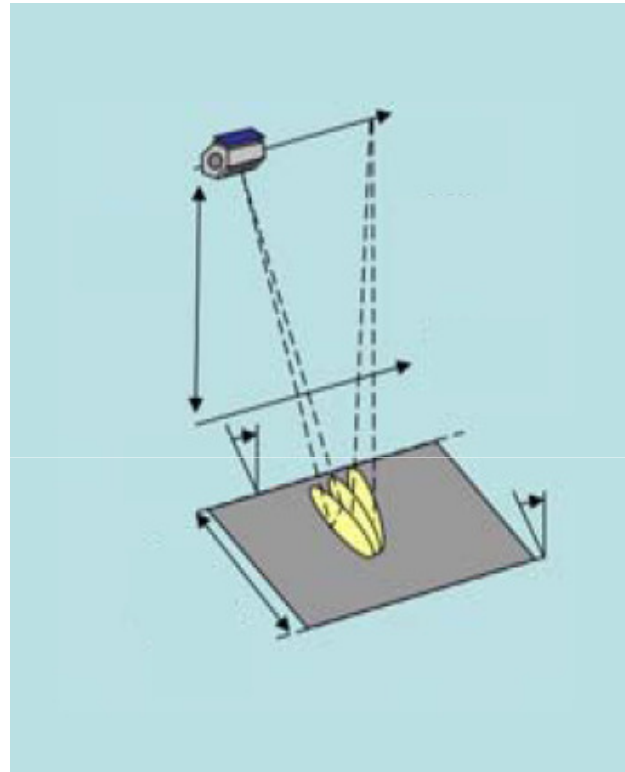
28

Pasovni način



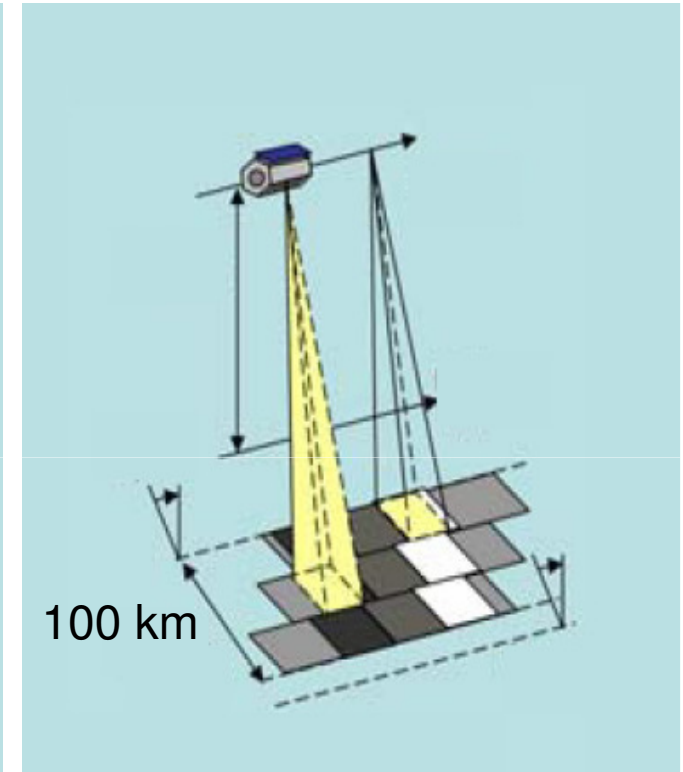
Resolucija 3m x 3m

Območni način



Resolucija 1,5m x 1,5m..3,5m.

Skansirni način

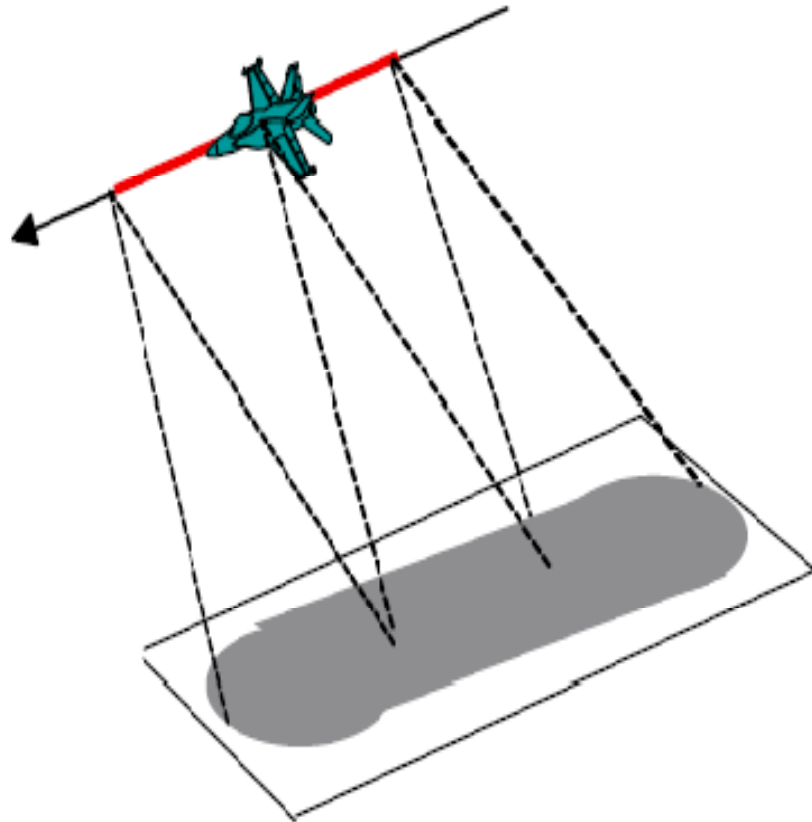


Resolucija 16m x 16m

- Enopasovni in (novejši) dvopasovni desno-levi način za pokrivanje področja
- Območni način za višjo resolucijo
- Skansirni način za pokrivanje širšega pasu

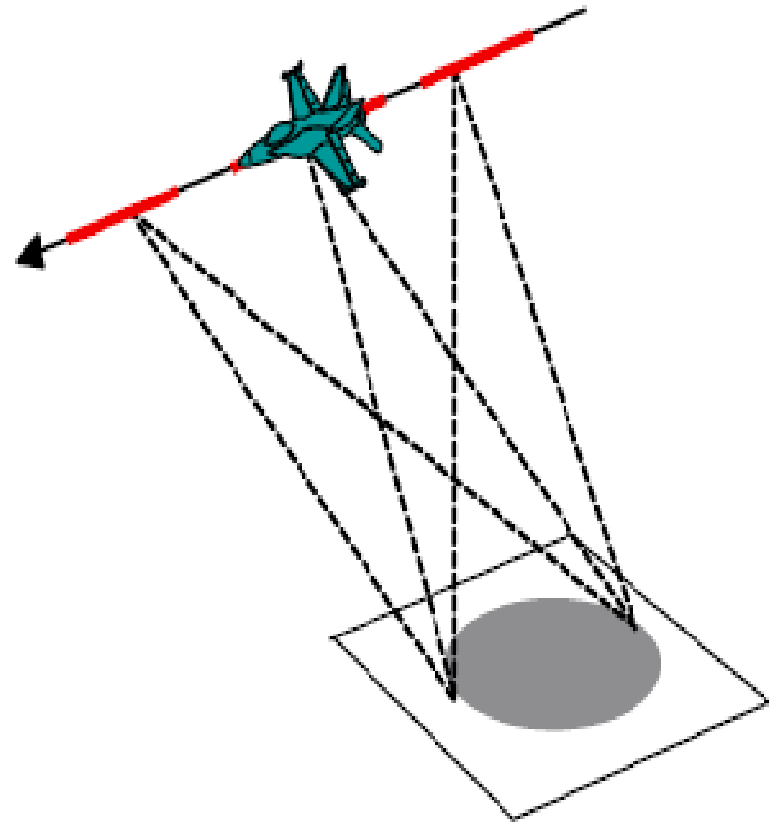
SAR – radar sintetične odprtine

Bočno pasovni SAR



Doseganje visoke resolucije na bočnem pasu med preletom

Bočni območni SAR



Doseganje najvišje resolucije na ožjem območju s fokusiranjem med preletom

Radarska interferometrija

Faza radarja:

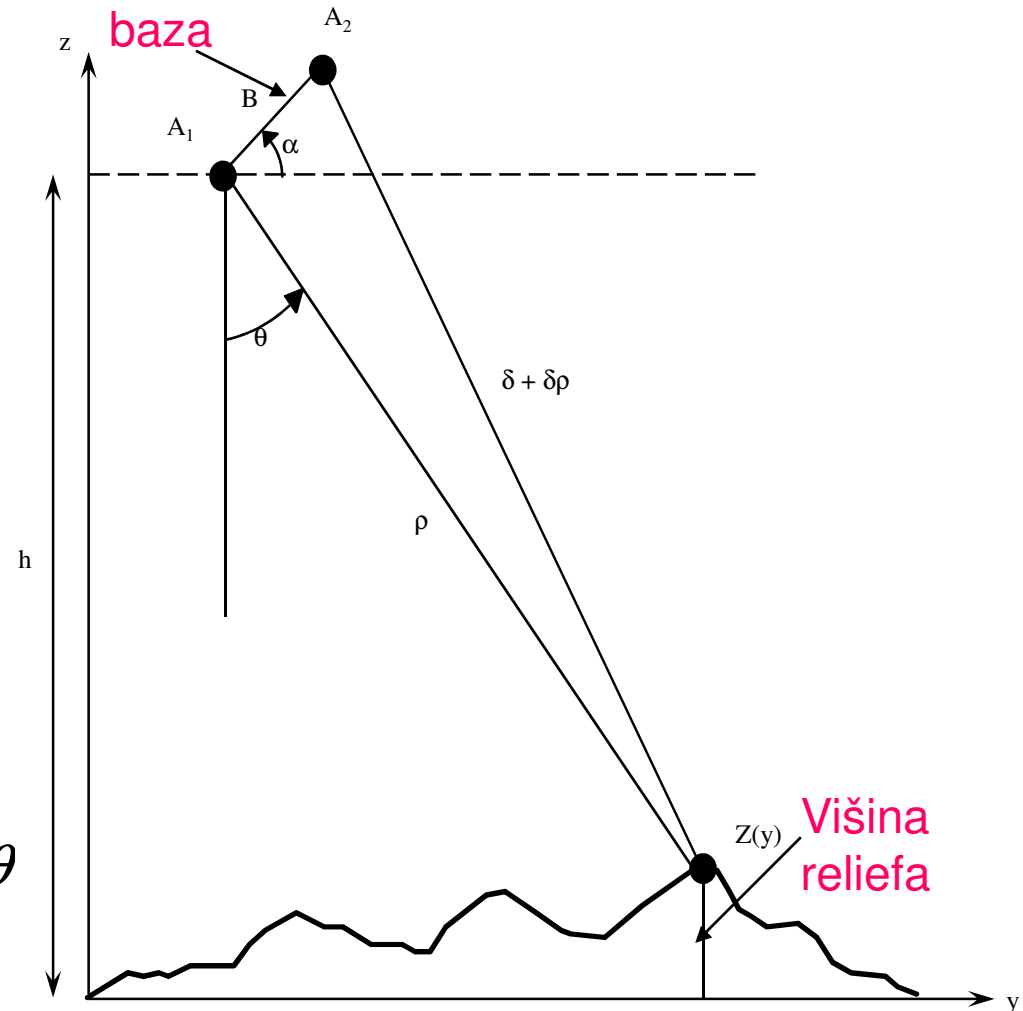
$$\phi_1 = \frac{4\pi}{\lambda} \rho, \quad \phi_2 = \frac{2\pi}{\lambda} (2\rho + \delta\rho)$$

$$\Rightarrow \Delta\phi = \frac{2\pi}{\lambda} \delta\rho \quad \delta\rho = \frac{\lambda \Delta\phi}{2\pi}$$

$\Delta\phi$ merjeno $\delta\rho$ računano

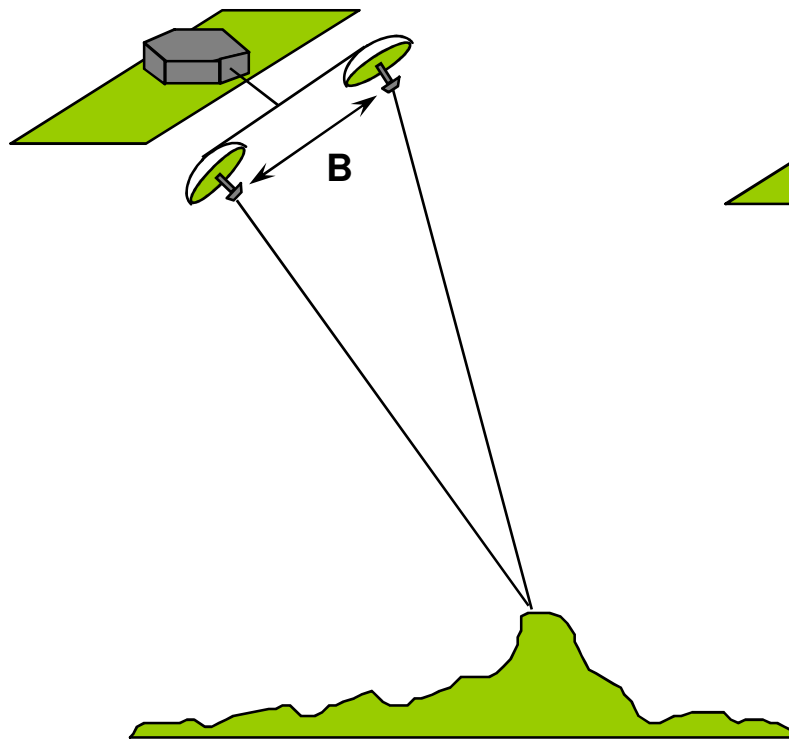
$$z(y) = h - \rho \cos \theta$$

$$z(y) = h - \frac{1}{2} \left\{ \frac{\left(\frac{\lambda \Delta\phi}{2\pi} \right)^2 - B^2}{B \sin(\alpha - \theta) - \left(\frac{\lambda \Delta\phi}{2\pi} \right)} \right\} \cos \theta$$

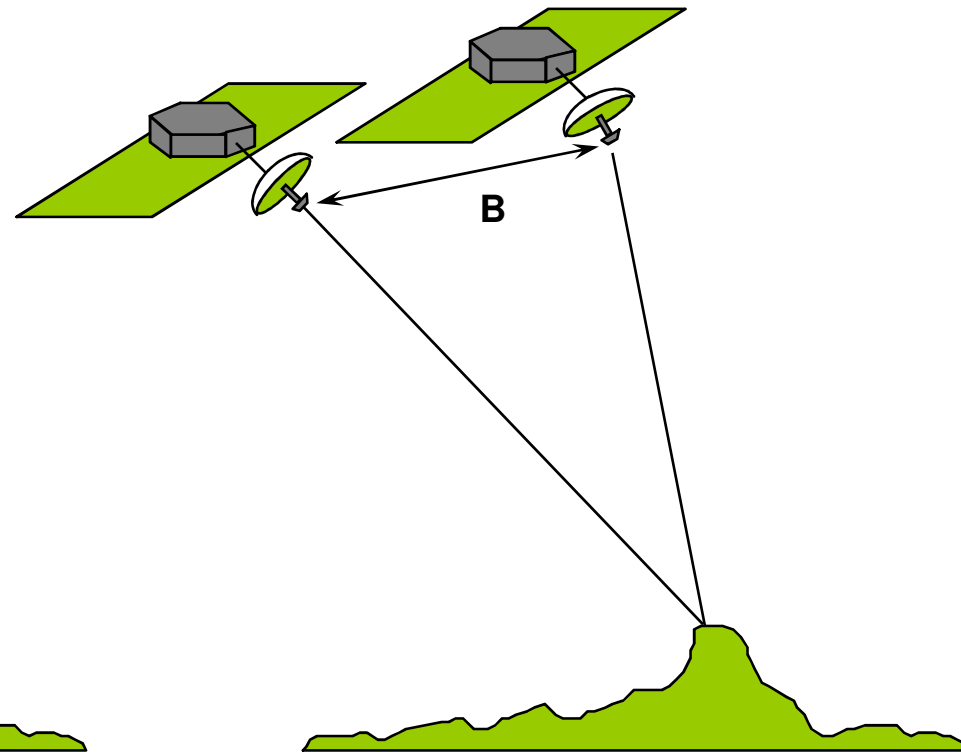


Hkratno zaznavanje

Radarska interferometrija

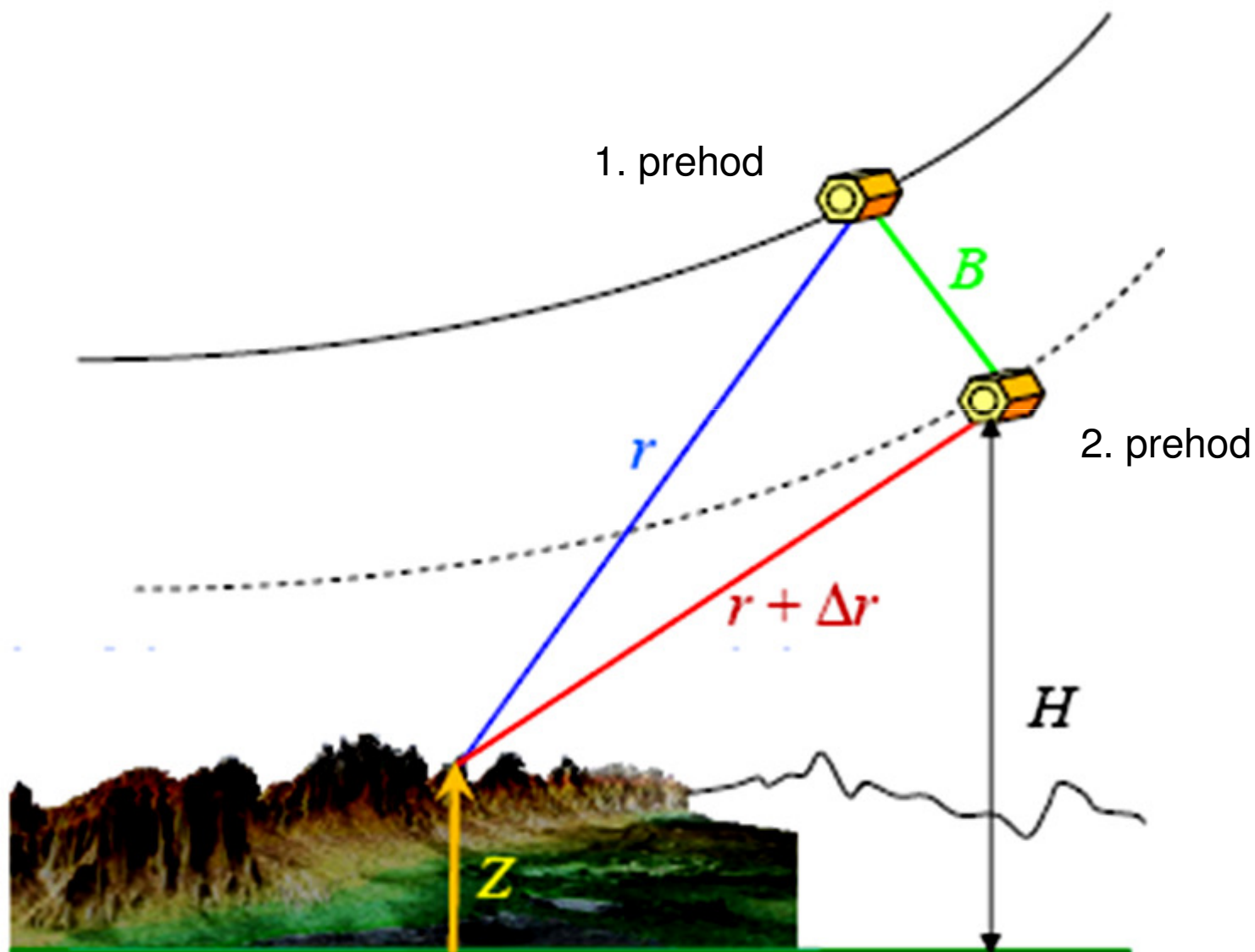


Hkratno zaznavanje
En satelit, dva SAR-a, en prelet

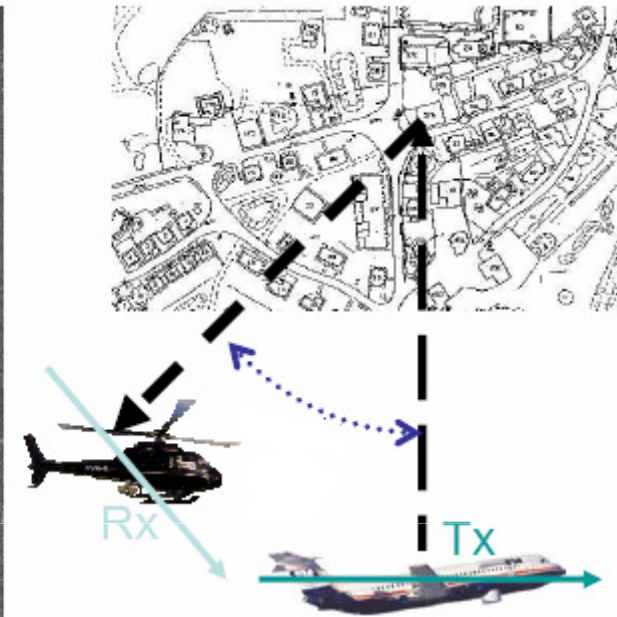
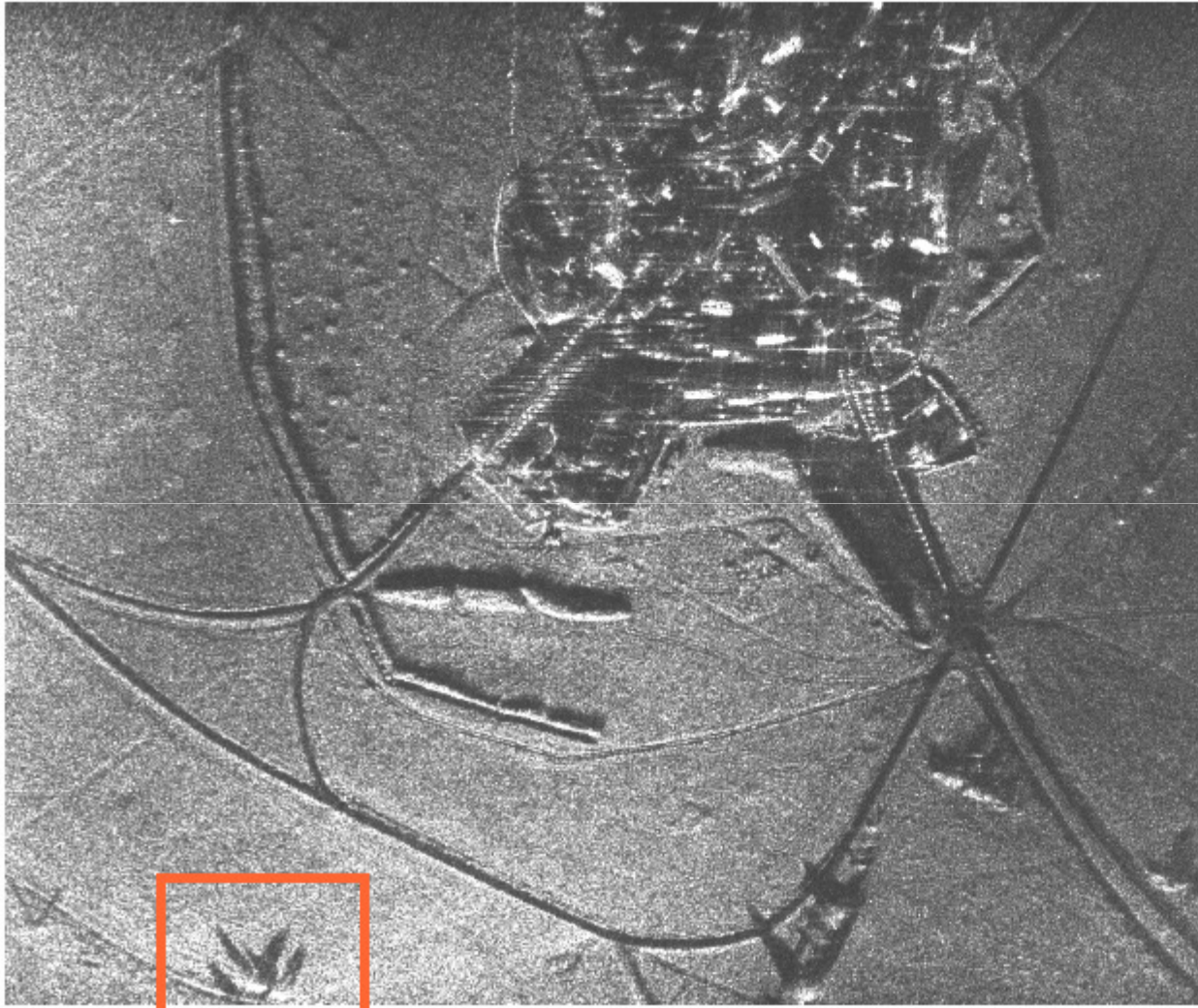


Ponovljeno zaznavanje
Dva satelita ali dva preleta

Diferenčni ponavljalni InSAR

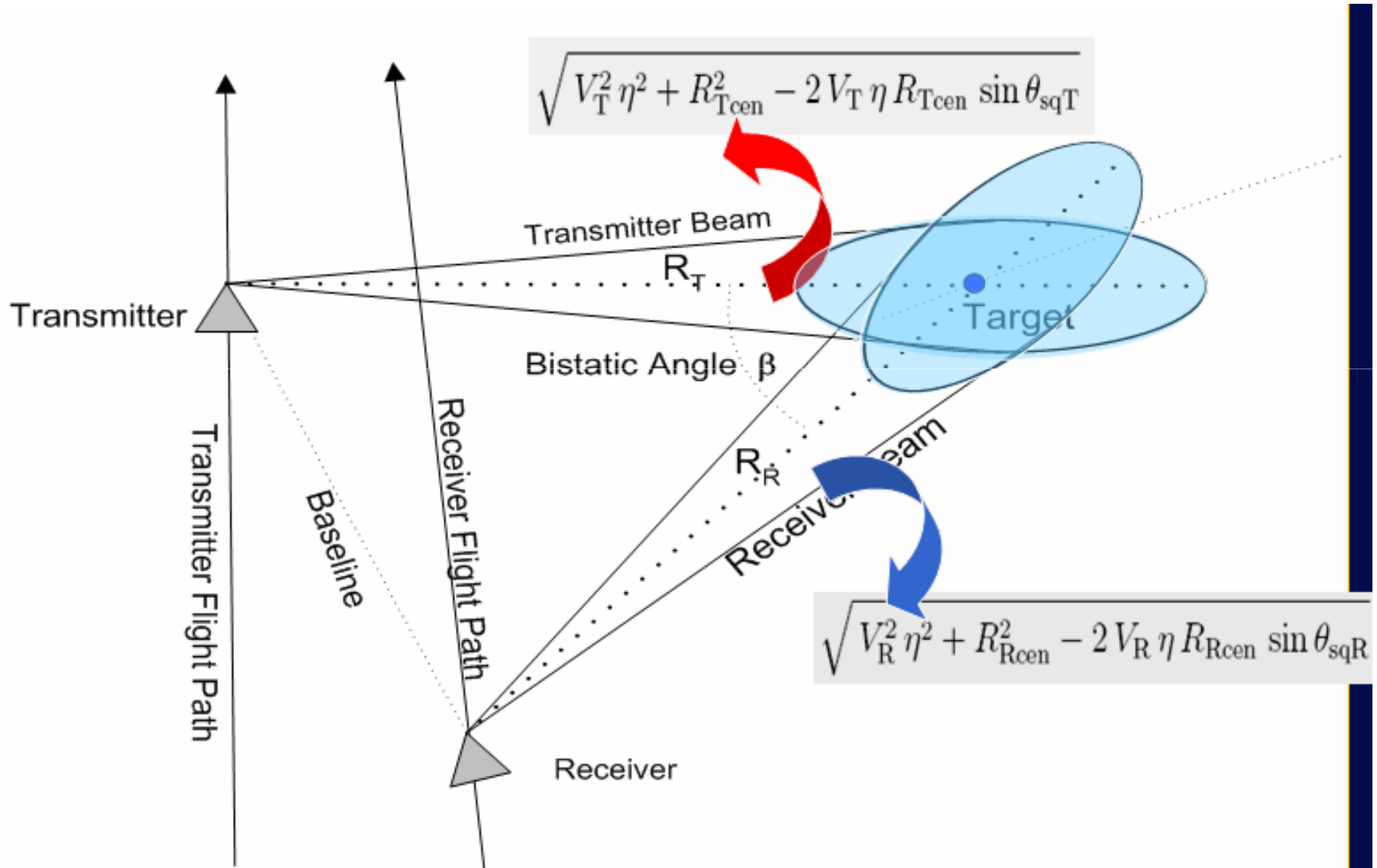


Bistatični SAR

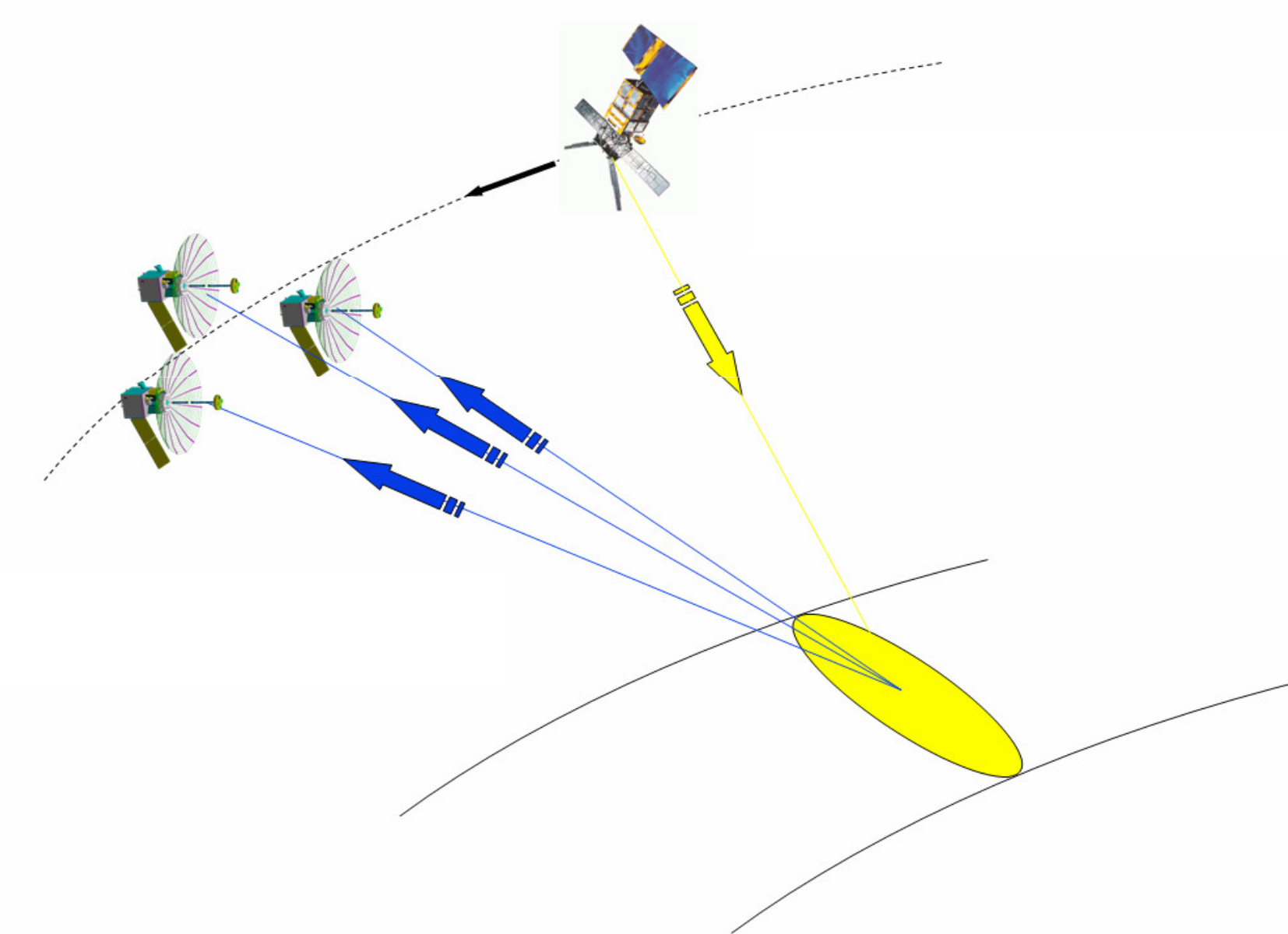


Dislociran oddajnik
in sprejemnik

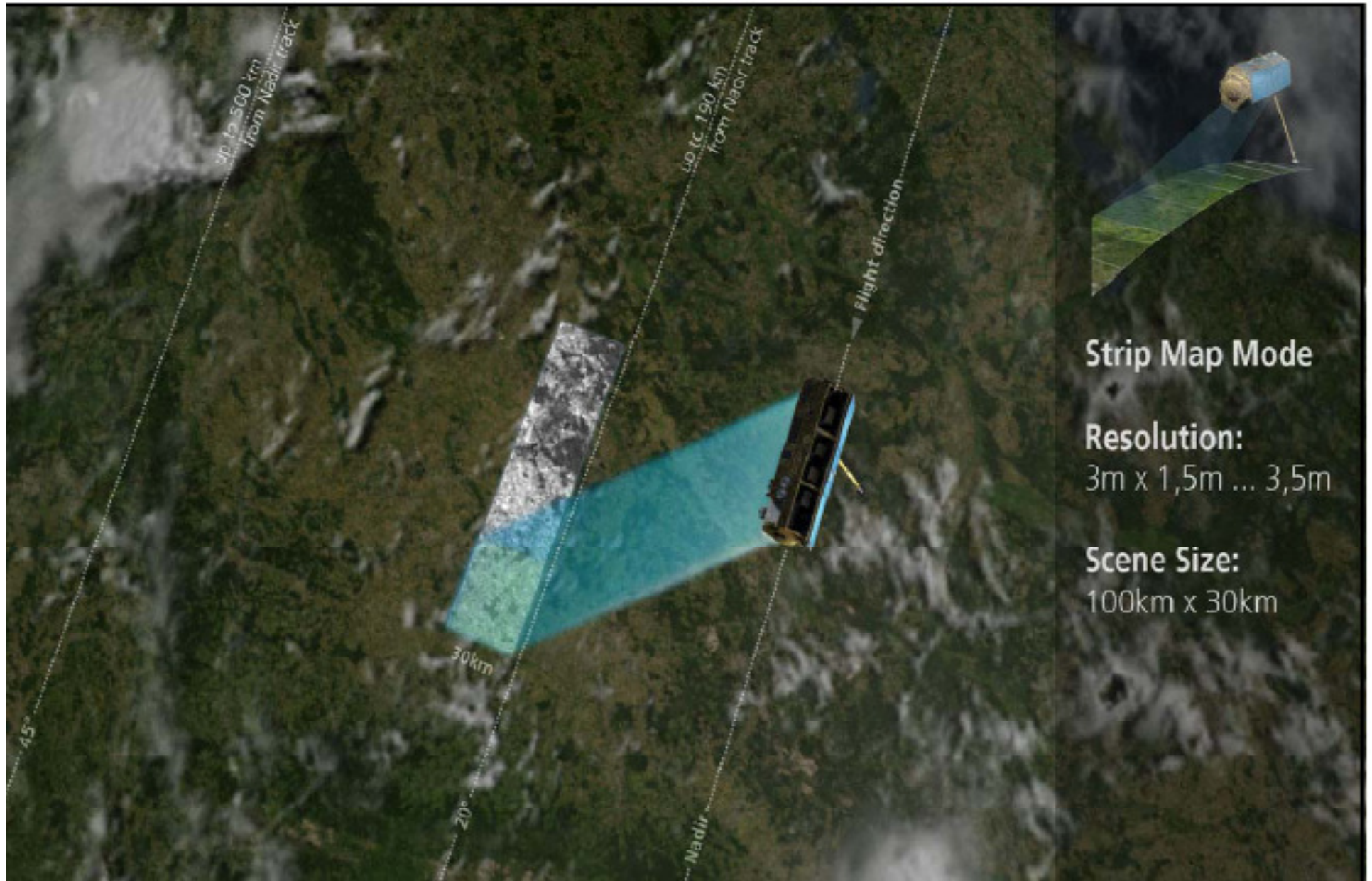
Bistatični SAR

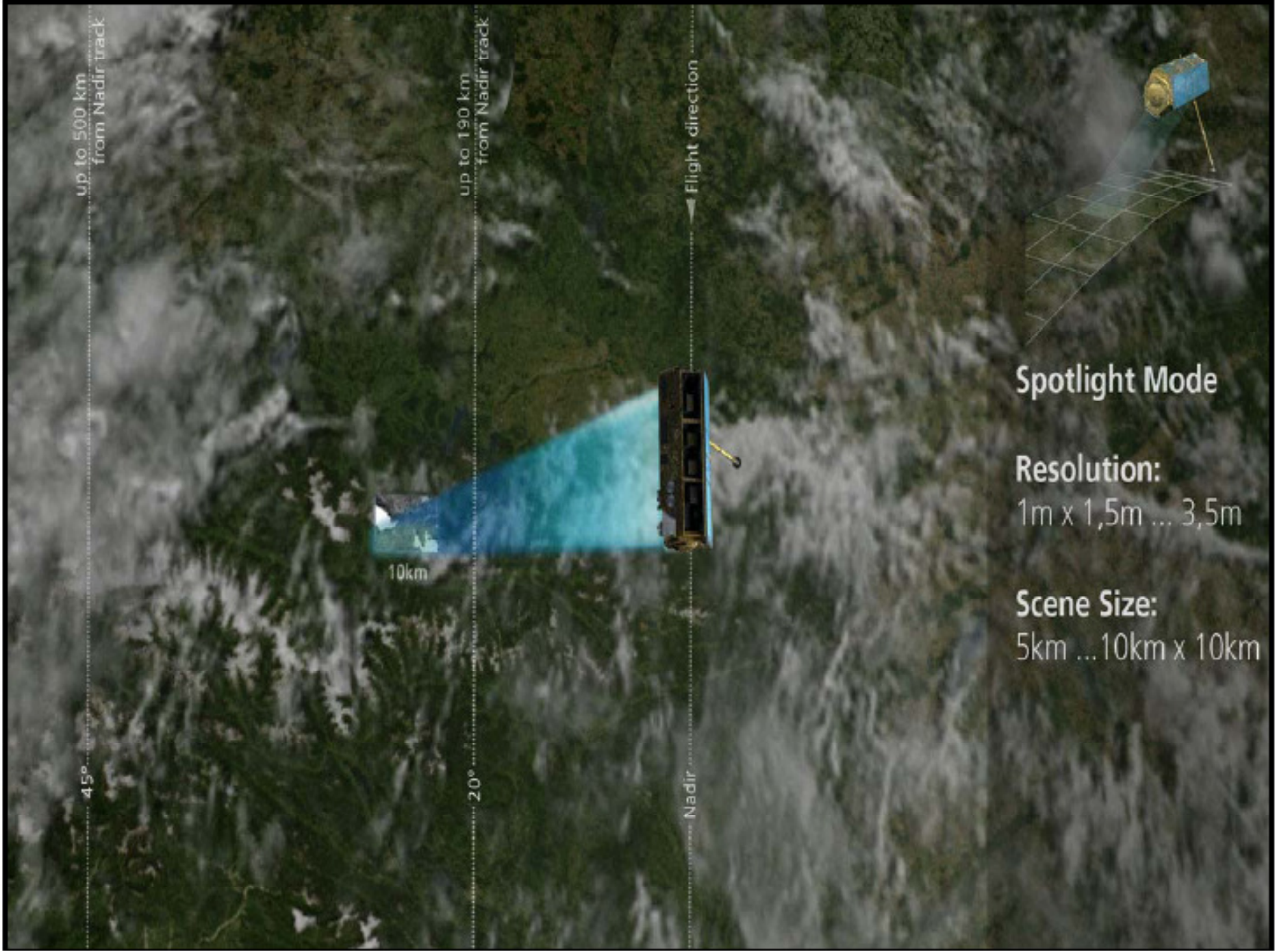


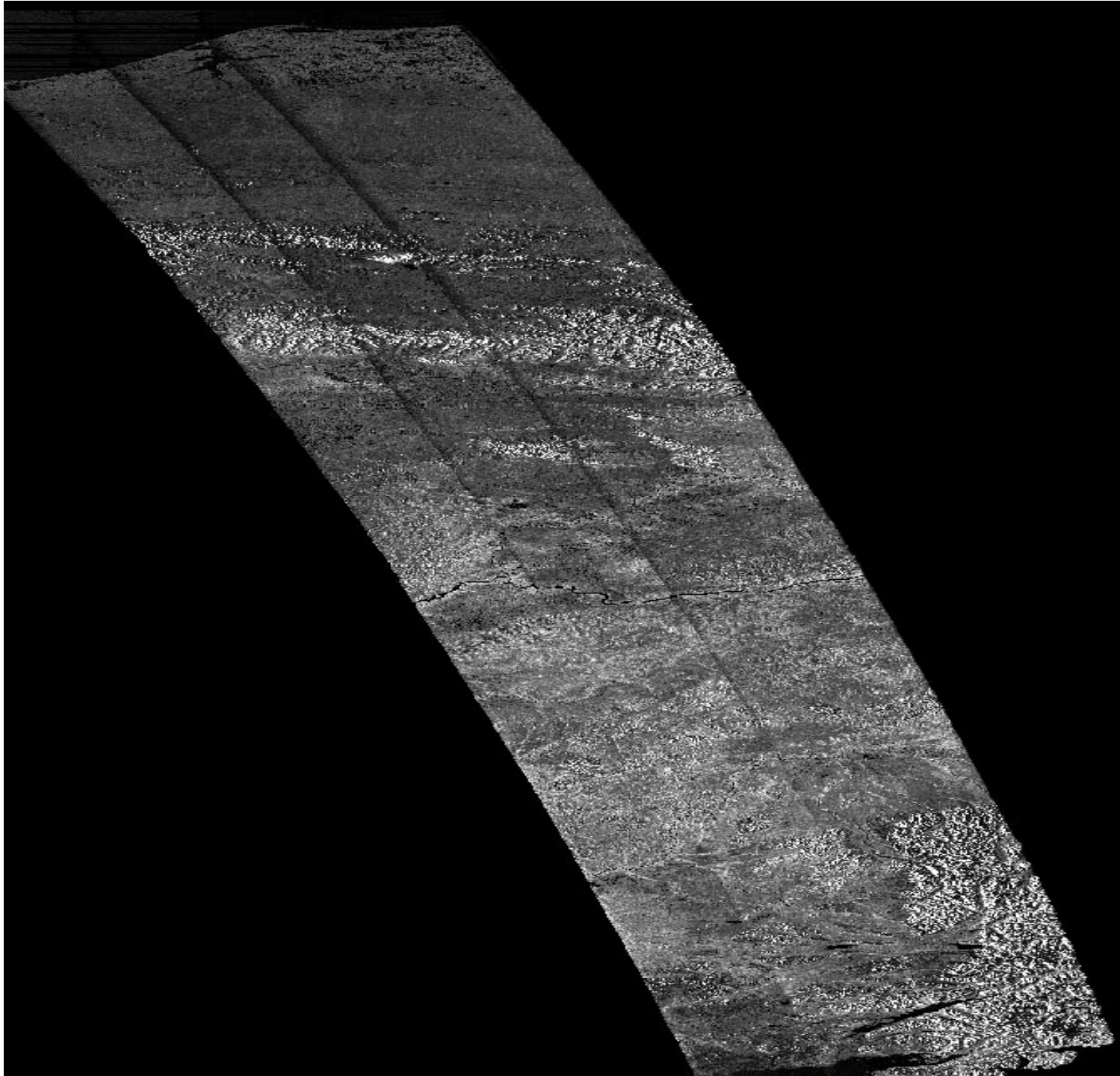
Bistatični SAR



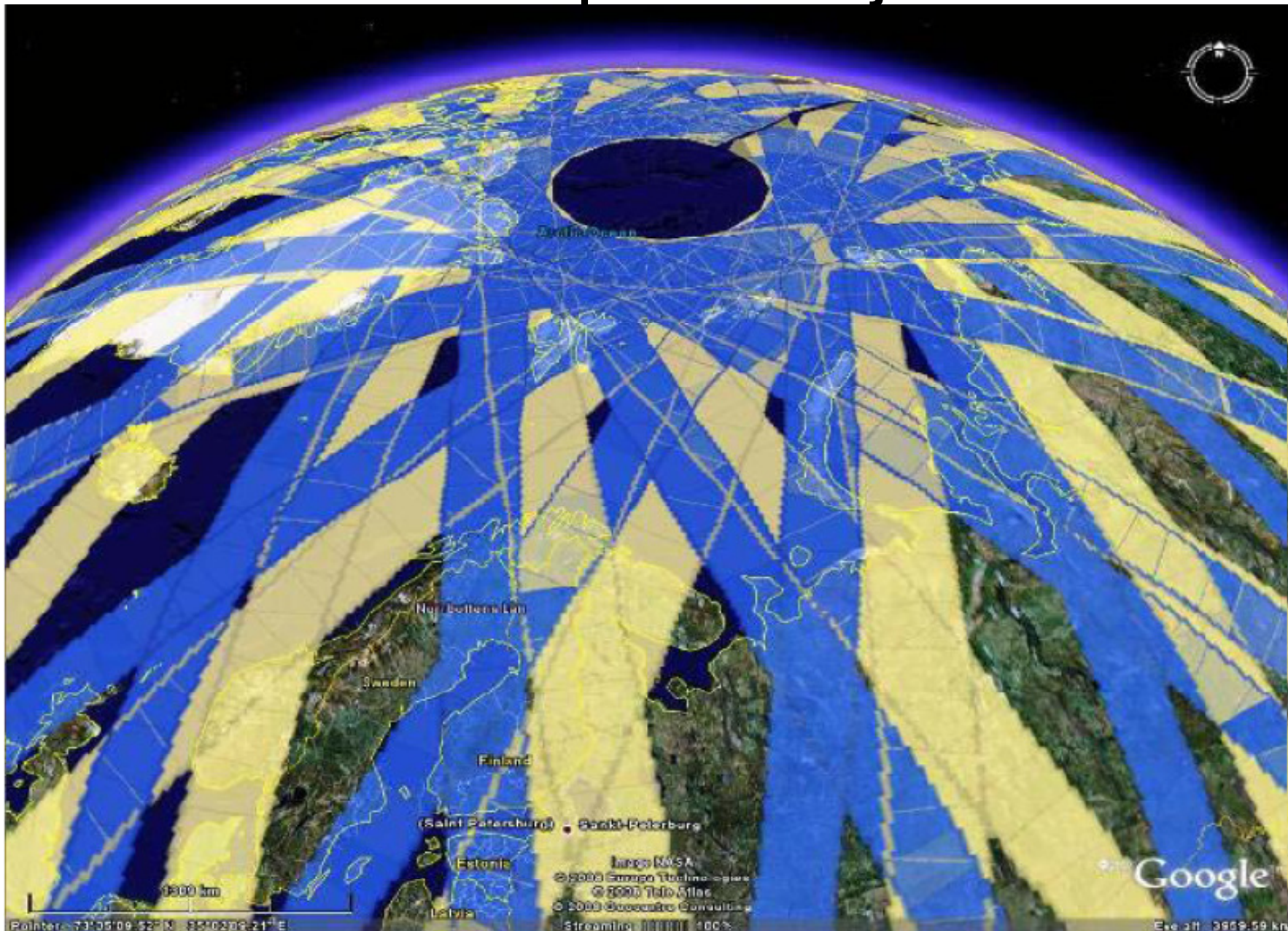
Pasovni način



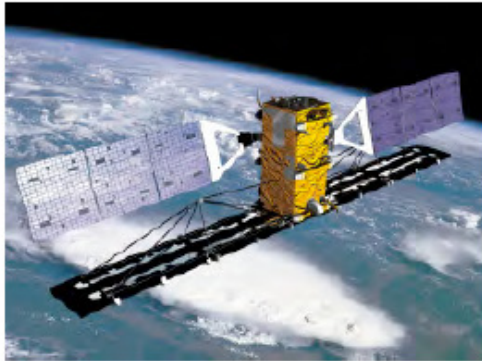




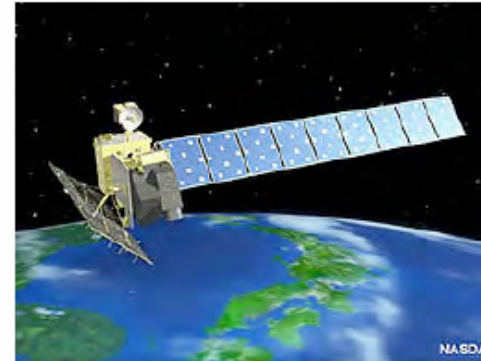
SAR pokrivanje



Novejše naprave PoISAR



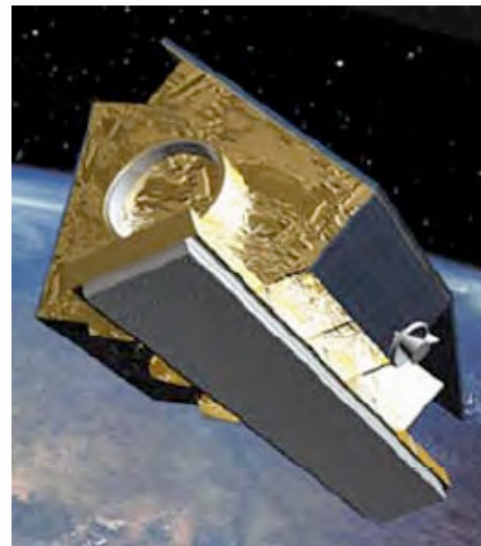
RADARSAT 2
CSA / MDA (CA)
2004
C-Band (Quad)



ALOS / PALSAR
NASDA / JAROS (J)
2003
L-Band
HH,VV, (HH,HV), (VV,VH)



ENVISAT / ASAR
ESA (EU)
2002
C-Band (Sngl / Twin)
HH, VV, (HH,VV),
(HH,HV), (HV,VV)



TERRASAR
BMBF / DLR / ASTRIUM
2005
X-Band (Twin)
(HH,VV), (HH,HV), (HV,VV)
L-Band (Quad)

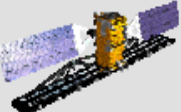
Amplituda, faza, polarizacija

Slikovni element = $\underbrace{A}_{\text{Amplituda SAR}} \exp(j \underbrace{\phi}_{\text{Faza InSAR}}) \underbrace{\vec{p}}_{\text{Polarizacija PolSAR}}$

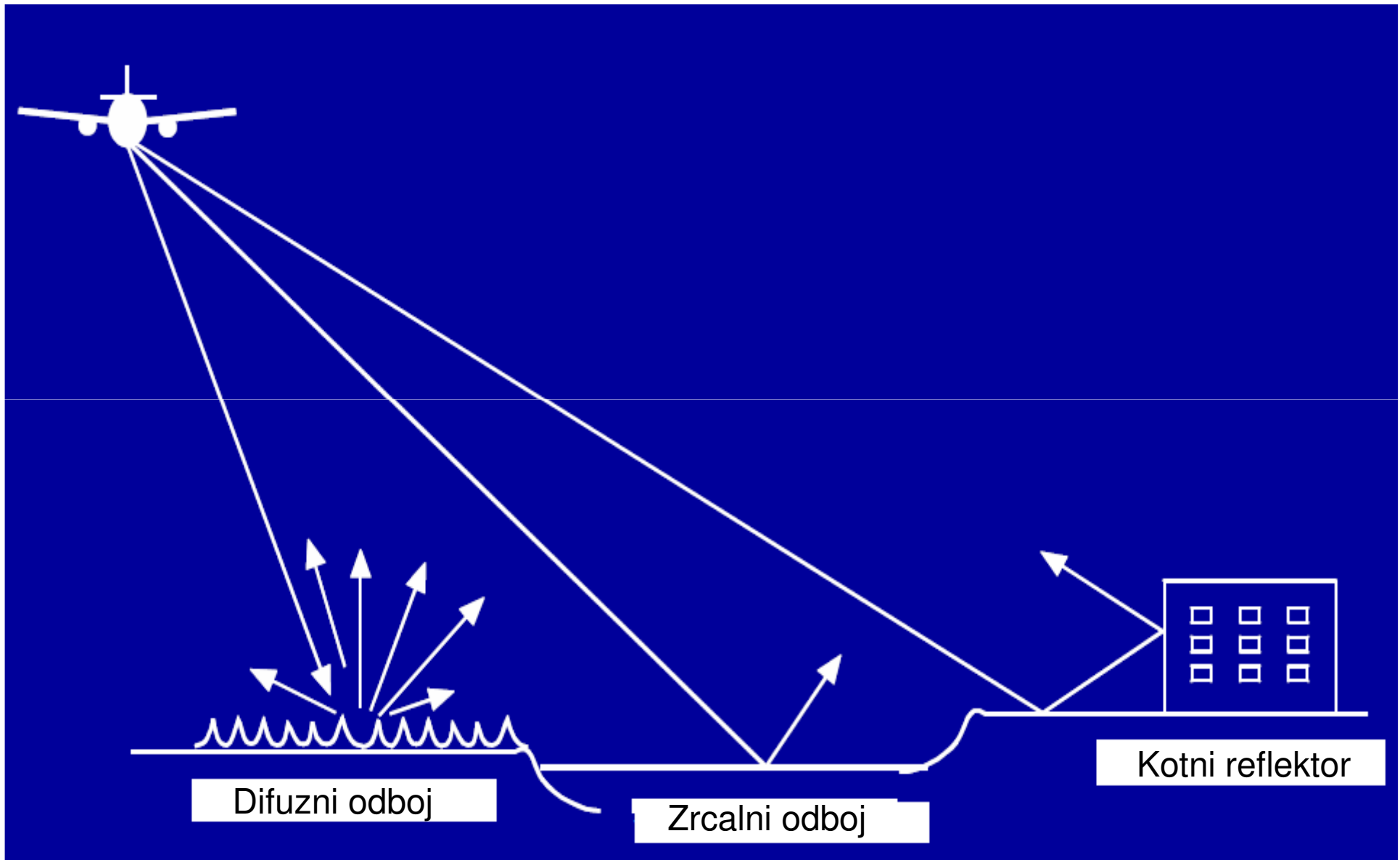
Pol-InSAR



Nekaj novejših sistemov Pol-InSAR

| | Design Life | Imaging frequency | Spatial resolution | Polarization | Look direction | Status |
|--|-------------|----------------------|--------------------|--|-------------------------|--------------------------|
| RADARSAT-2  | 7 years | C-Band, 5.405 GHz | 3 to 100 meters | Single (HH, VV, VH, HV) Dual (HH/ HV, VV/VH) Polarimetric | Left- and right-looking | Launch 2007 |
| | | | | | | V razvoju je RadarSAT-3. |
| RADARSAT-1 | 5 years | C-Band, 5.3 GHz | 10 to 100 m | Single HH | Right-looking | In operation (Since 95) |
| Envisat ASAR | 5 years | C-Band, 5.331 GHz | 30 to 1000 meters | Single (HH, VV) Alternating (VV/HH, VV/VH, HH/HV) | Right-looking | In operation (Since 02) |
| TerraSAR-X | 5 years | X-Band, 9.650 GHz | 1 to 15 meters | Single (HH, VV) Dual (VV/HH, VV/VH, HH/HV) Polarimetric (exp.) | Left- and right-looking | Launch 2006 |
| ALOS PALSAR | 5 years | L-Band, 1.27 GHz | 10 to 100 meters | Single (HH, VV) Dual (HH/ HV, VV/VH) Polarimetric (exp.) | Right-looking | Launched in January 2006 |

SAR – vrste odboja



SAR - amplituda

Amplituda, posnetek Freiburg

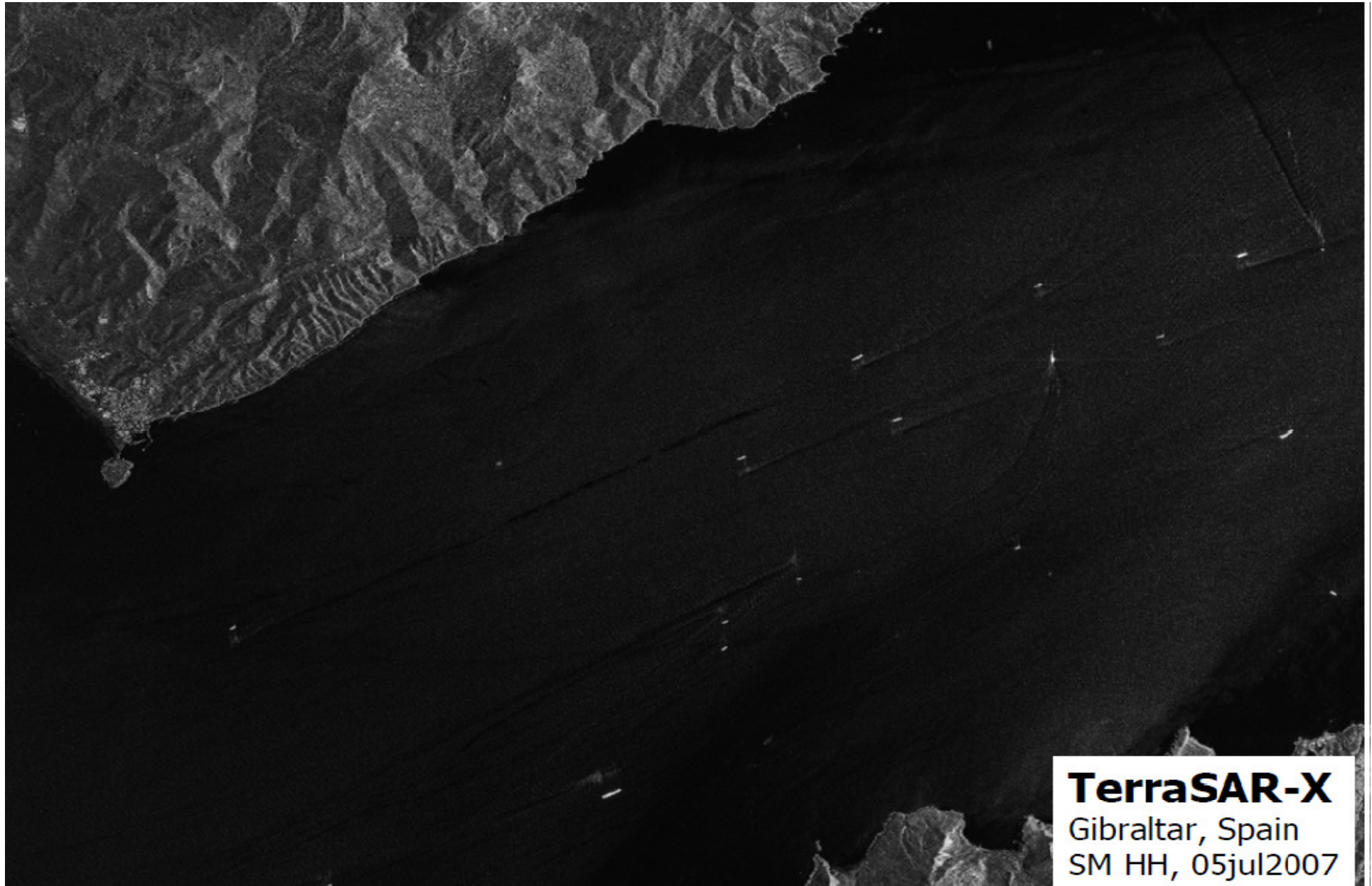


SAR -amplituda

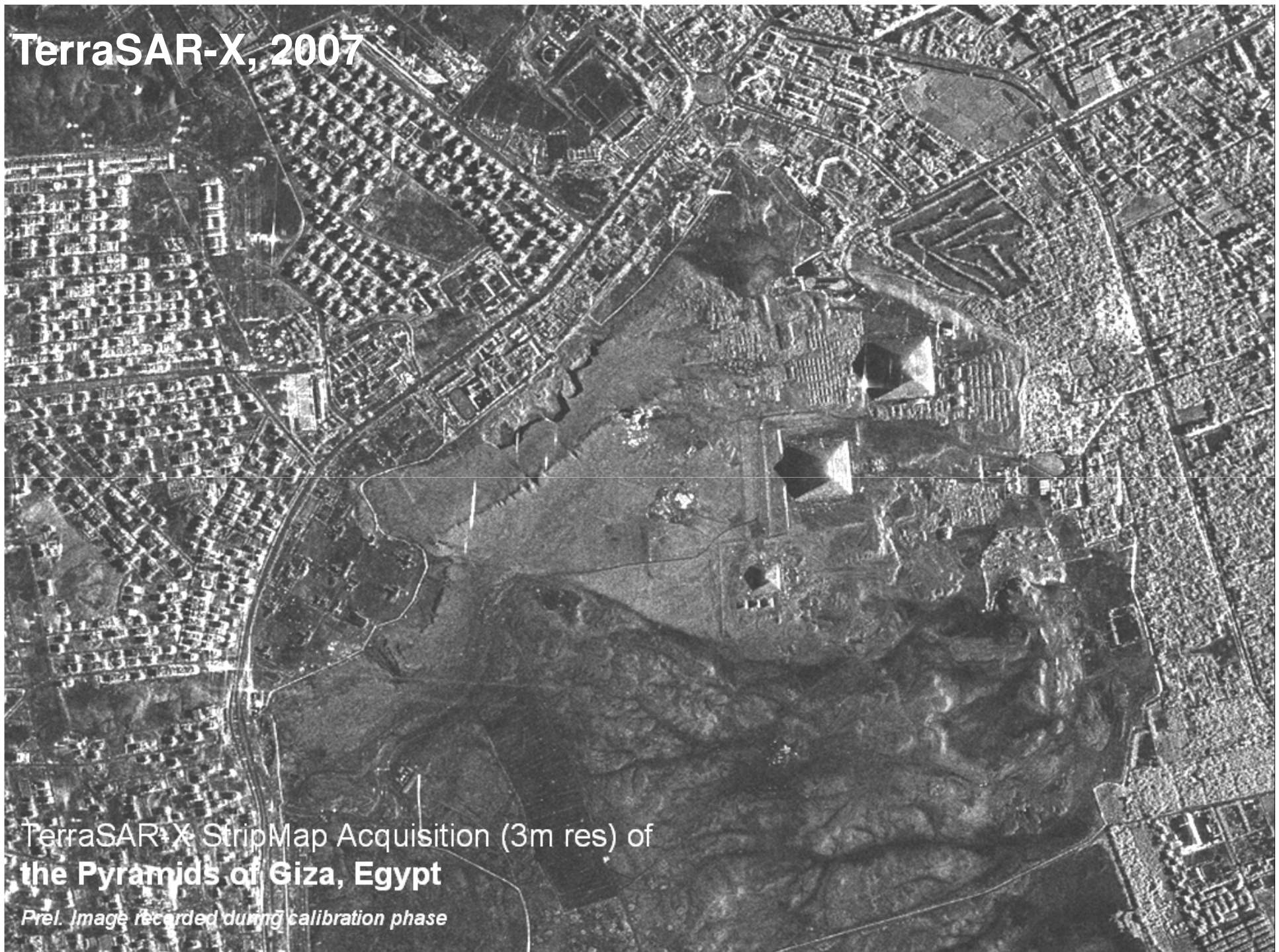


TerraSAR-X
Bonn, Germany
Spotlight, 15jun2007

SAR - amplituda



TerraSAR-X, 2007



TerraSAR-X StripMap Acquisition (3m res) of
the Pyramids of Giza, Egypt

Prel. Image recorded during calibration phase

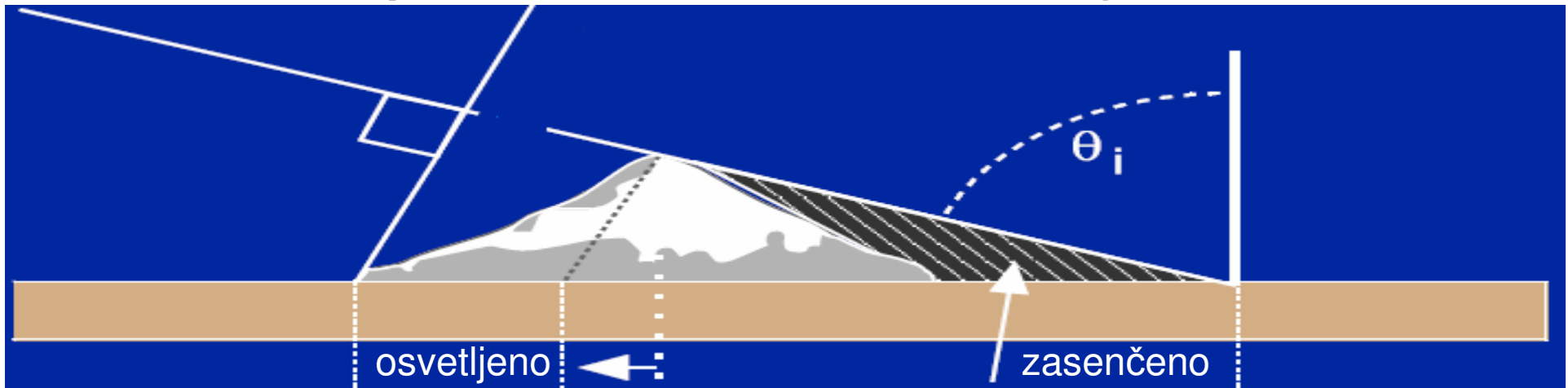
TerraSAR-X, 2007



Mombasa (Kenya) – 1m res

Prelet čez piramide; kako razlagamo slike

49



- gladka površina tal - temno
- hrapava površina tal - svetlo
- mirna vodna površina - temno
valovita vodna površina svetlo
- hribi – svetleje proti radarju,
temneje stran od radarja
- objekti (stavbe) – svetle točke
- trirobni reflektor – žareče točke



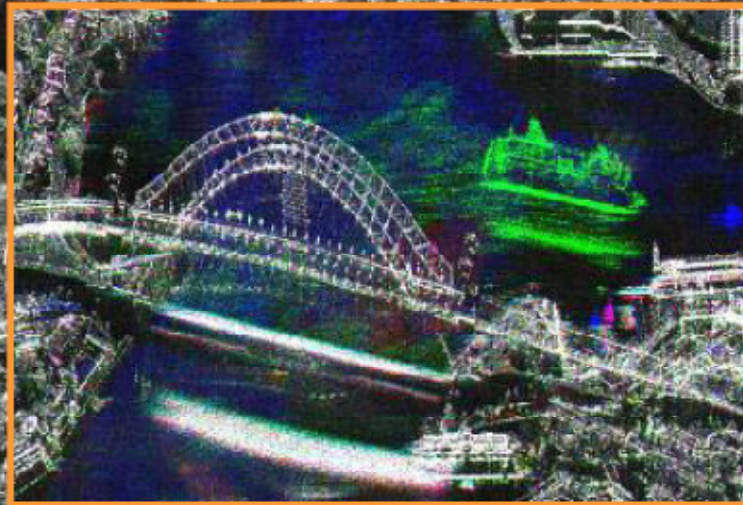
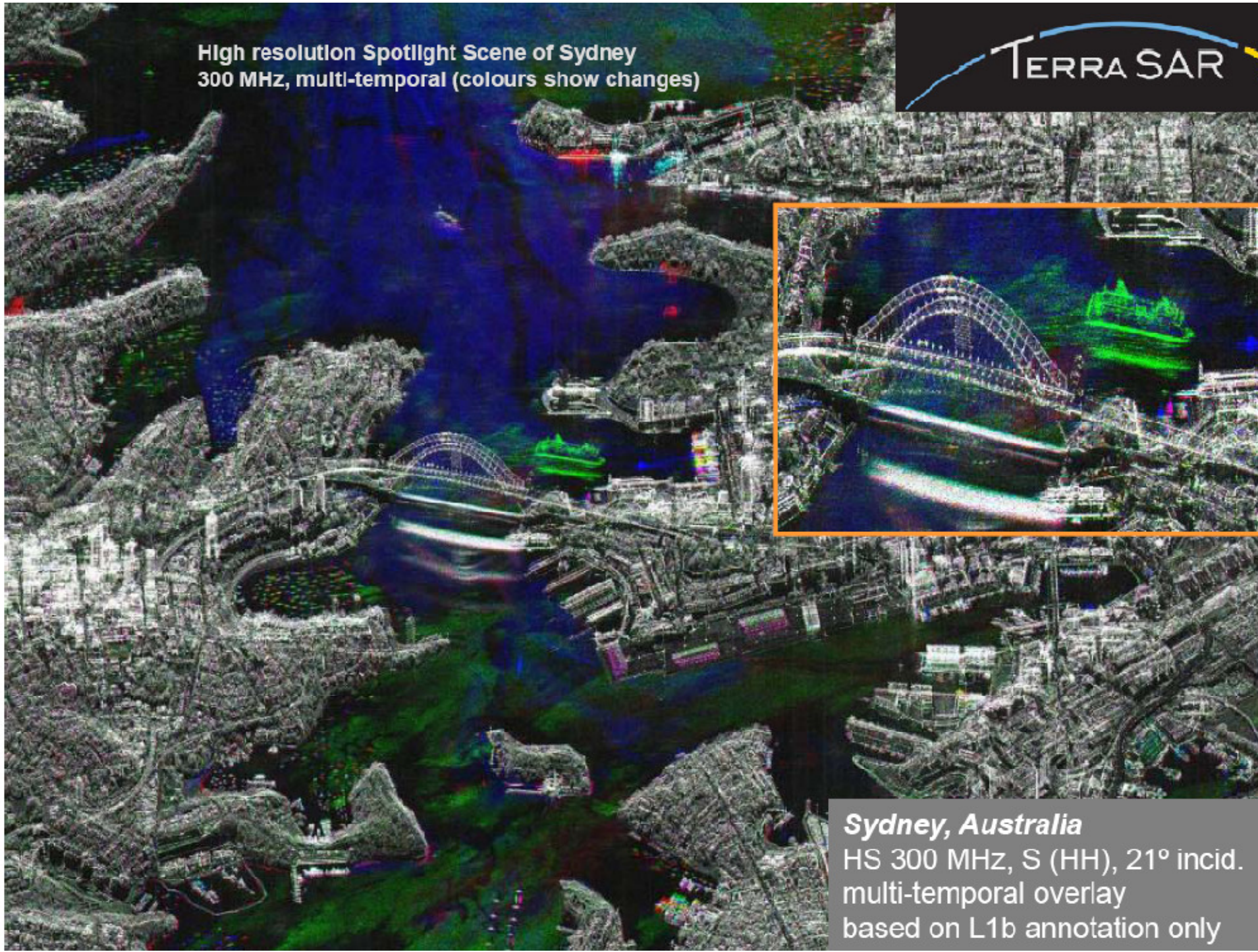
TerraSAR-X

- 1 m Spotlight Image
- Sydney, Australia

Prel. Image recorded during calibration phase



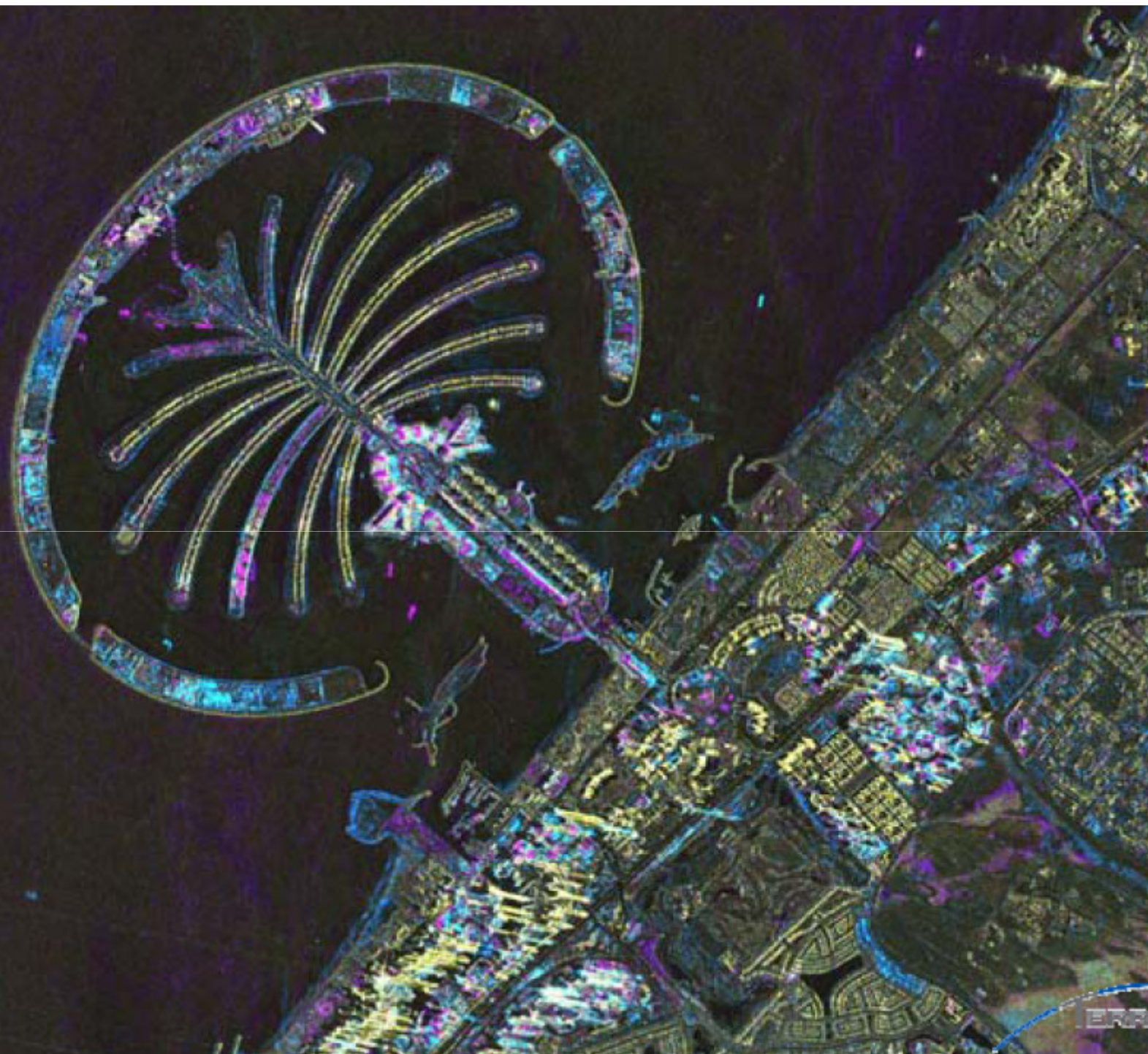
High resolution Spotlight Scene of Sydney
300 MHz, multi-temporal (colours show changes)



Sydney, Australia
HS 300 MHz, S (HH), 21° incid.
multi-temporal overlay
based on L1b annotation only

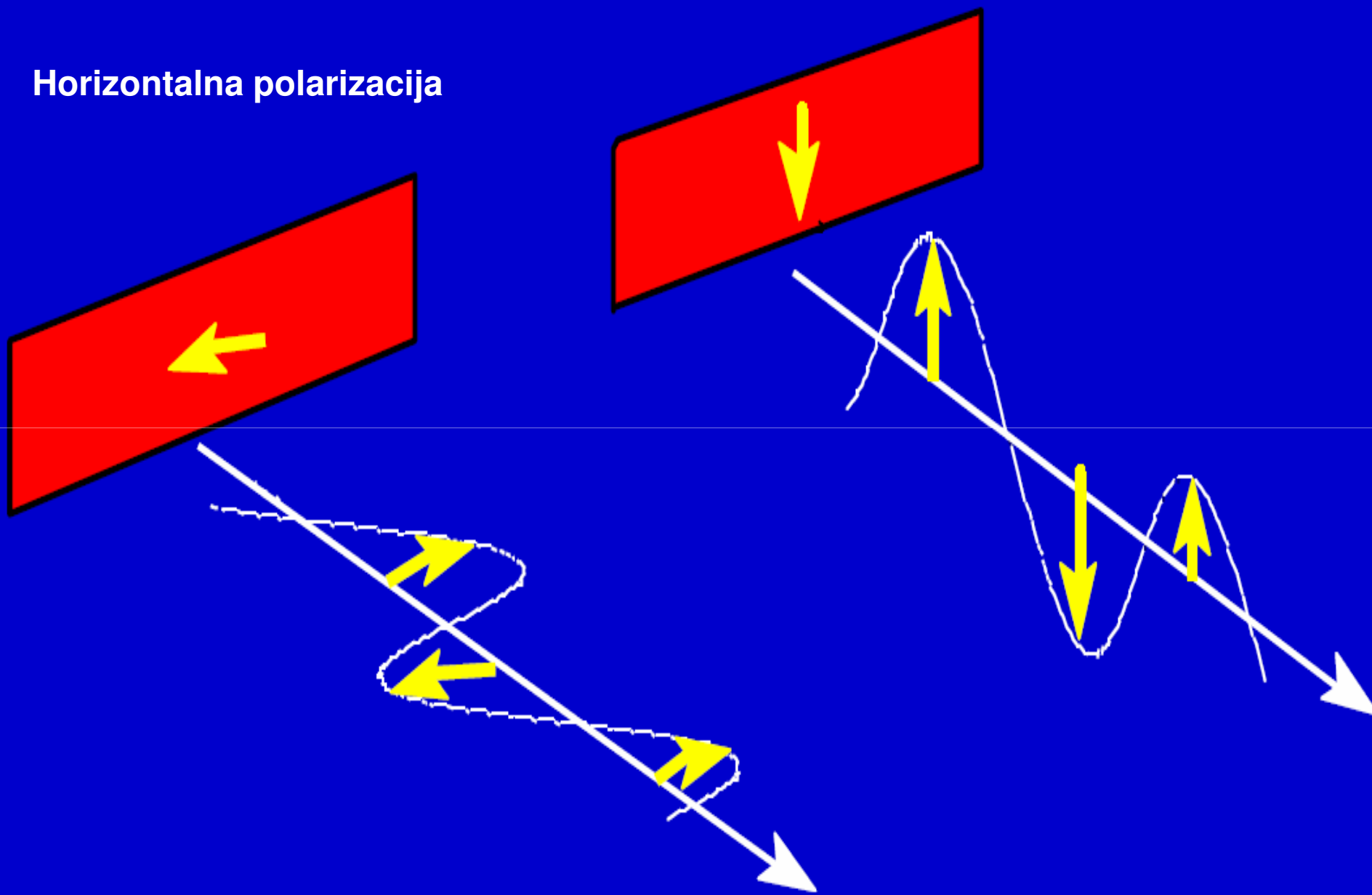
Dubai
Stripmap
VV-pol.

- 26. Juni 2007
- 7. April 2008
- Difference

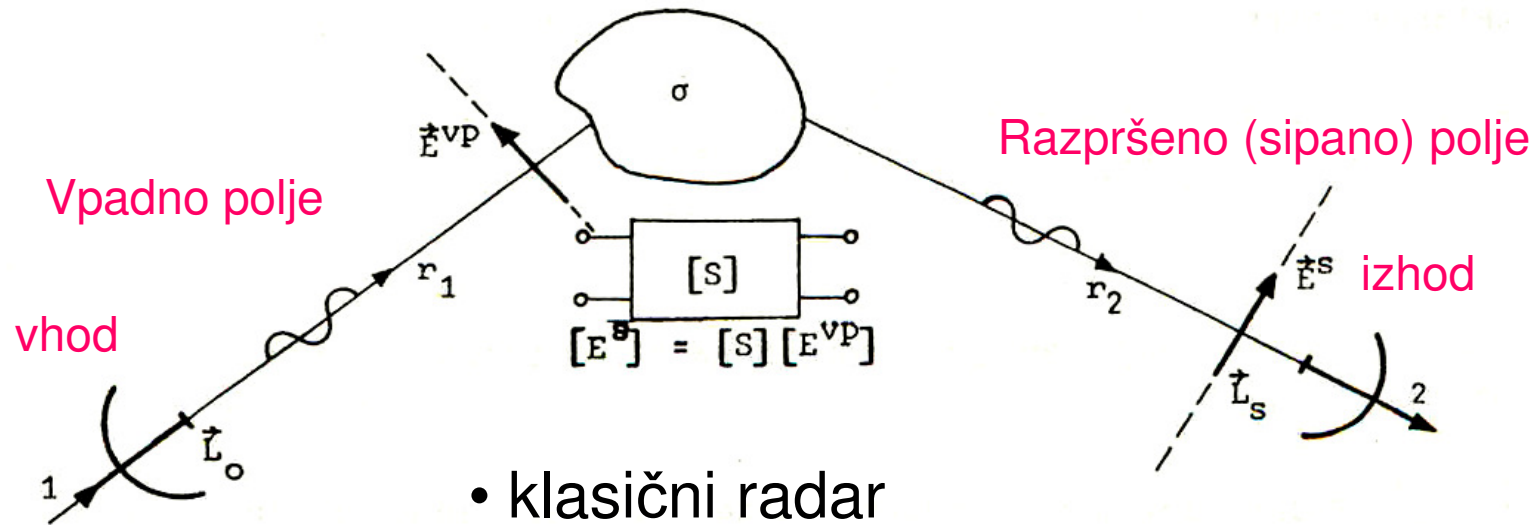


Vertikalna polarizacija

Horizontalna polarizacija



Polarizacijska matrika razpršitve



Linearne enačbe:

$$E_1^S = S_{11}E_1^{VP} + S_{12}E_2^{VP}$$

$$E_2^S = S_{21}E_1^{VP} + S_{22}E_2^{VP}$$

ali

Matrična enačba:

$$\begin{bmatrix} E_1^S \\ E_2^S \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} E_1^{VP} \\ E_2^{VP} \end{bmatrix}$$

Napetost izražena z efektivnimi dolžinami:

$$U_{o2} = \frac{jIZ_o}{2\lambda r_1} [L_{1s}^* \quad L_{2s}^*] \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} L_{10} \\ L_{20} \end{bmatrix} = \frac{jIZ_o}{2\lambda r_1} [L_s^*]^T [S] [L_o].$$

Polarimetrična formula

Odbito (razpršeno, sipano) polje

$$E_s = \frac{e^{ikr}}{r} SE_i$$

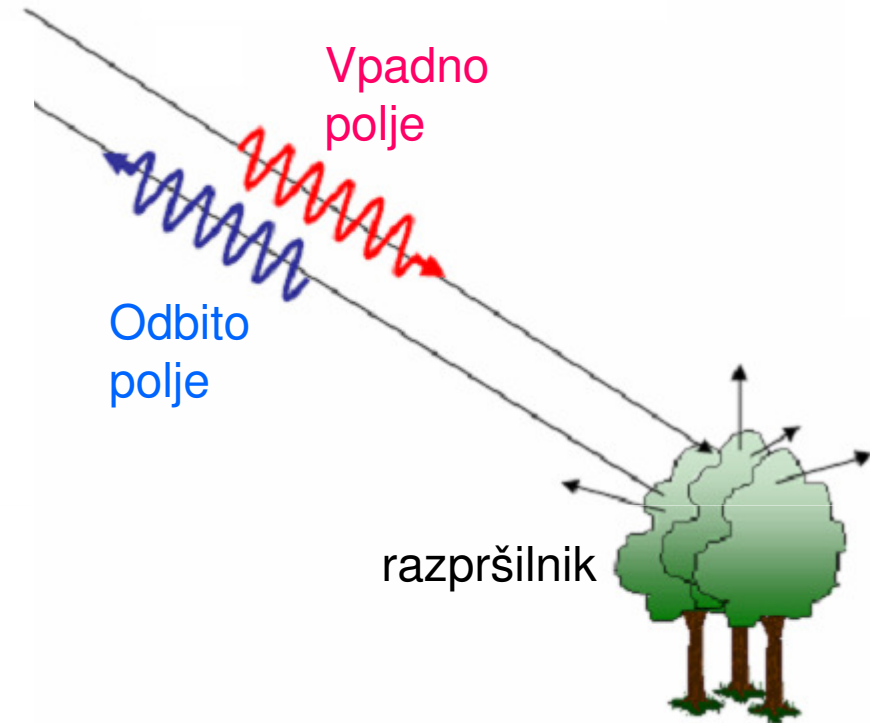
Vertikalna in horizontalna komponenta

$$\begin{bmatrix} E_{sv} \\ E_{sh} \end{bmatrix} = \frac{e^{ikr}}{r} \begin{bmatrix} S_{vv} & S_{vh} \\ S_{hv} & S_{hh} \end{bmatrix} \begin{bmatrix} E_{iv} \\ E_{ih} \end{bmatrix}$$

Parameter polarizacijske matrike

$$S_{ij} = |S_{ij}| e^{i\phi_{ij}} \quad (\text{velikost in faza})$$

$$S_{vh} = S_{hv} \quad (\text{recipročnost})$$



Polarizacijska matrika vsebuje informacijo o bio-fizikalnih lastnostih površine tal
 Pol-InSAR ugotavlja polarizacijsko matriko porazdelitve, Pri tem je pomembna:

- orientacija razpršilnikov glede na radar
- naključnost porazdelitve razpršilnikov.

Kovariančná matrika v polarimetriji

$$\begin{bmatrix} E'_x \\ E'_y \end{bmatrix} = K \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_x^t \\ E_y^t \end{bmatrix}$$

$$\vec{k}_B = [S_{HH}, S_{HV}, S_{VH}, S_{VV}]^T$$

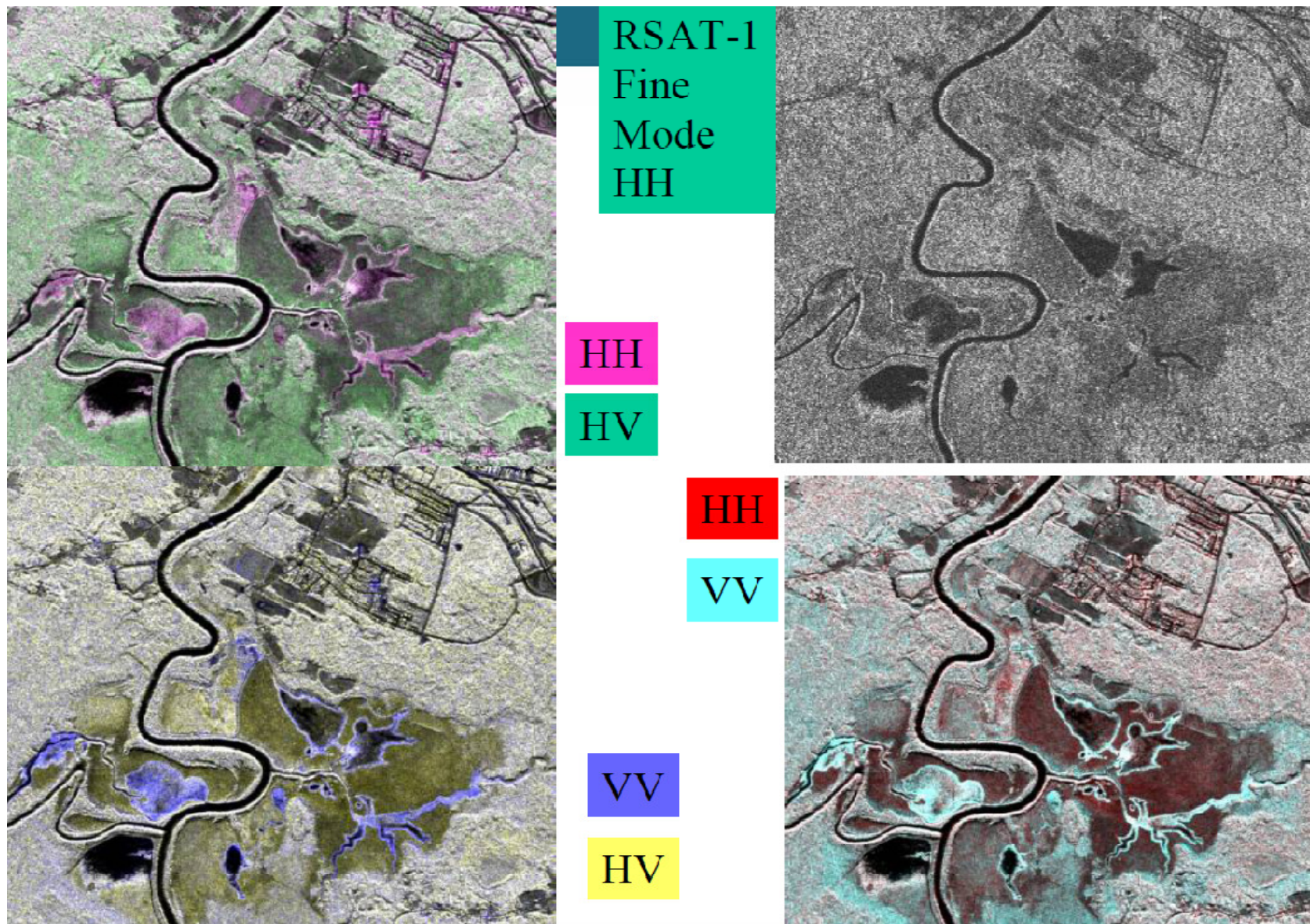
$$[C]_{4 \times 4} = \left\langle \vec{k}_B \vec{k}_B^t \right\rangle = \begin{bmatrix} \langle |S_{HH}|^2 \rangle & \langle S_{HH} S_{HV}^* \rangle & \langle S_{HH} S_{VH}^* \rangle & \langle S_{HH} S_{VV}^* \rangle \\ \langle S_{HV} S_{HH}^* \rangle & \langle |S_{HV}|^2 \rangle & \langle S_{HV} S_{VH}^* \rangle & \langle S_{HV} S_{VV}^* \rangle \\ \langle S_{VH} S_{HH}^* \rangle & \langle S_{VH} S_{HV}^* \rangle & \langle |S_{VH}|^2 \rangle & \langle S_{VH} S_{VV}^* \rangle \\ \langle S_{VV} S_{HH}^* \rangle & \langle S_{VV} S_{HV}^* \rangle & \langle S_{VV} S_{VH}^* \rangle & \langle |S_{VV}|^2 \rangle \end{bmatrix}$$

Prikaz odboja na polarizaciji H in V⁵⁹

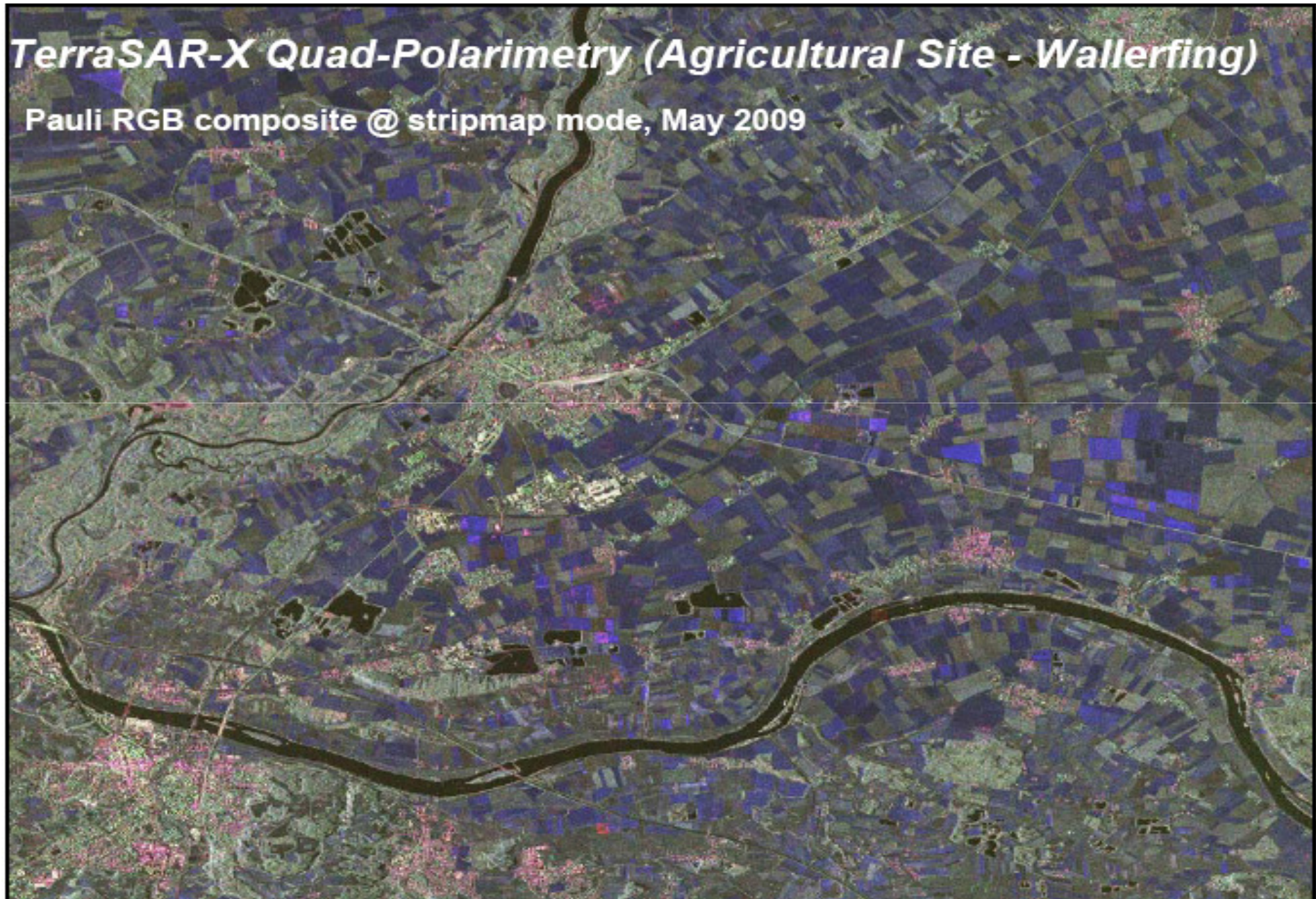
HH rdeče
VV zeleno



Posnetki tal pri različnih polarizacijah ⁶⁰



TeraSAR-X ; primer 4-pol. snemanja ⁶¹

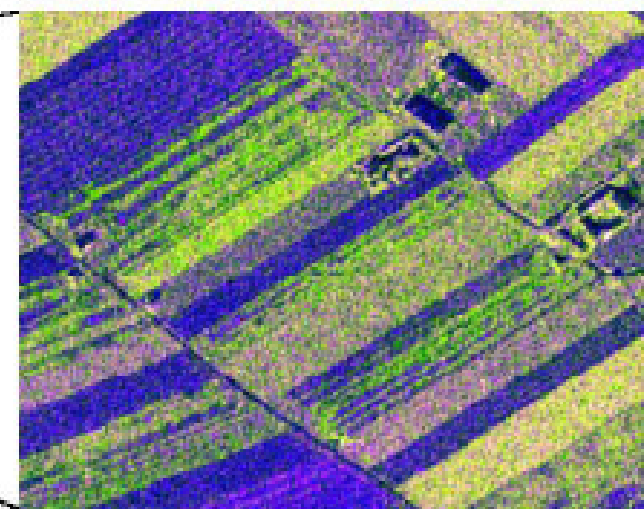
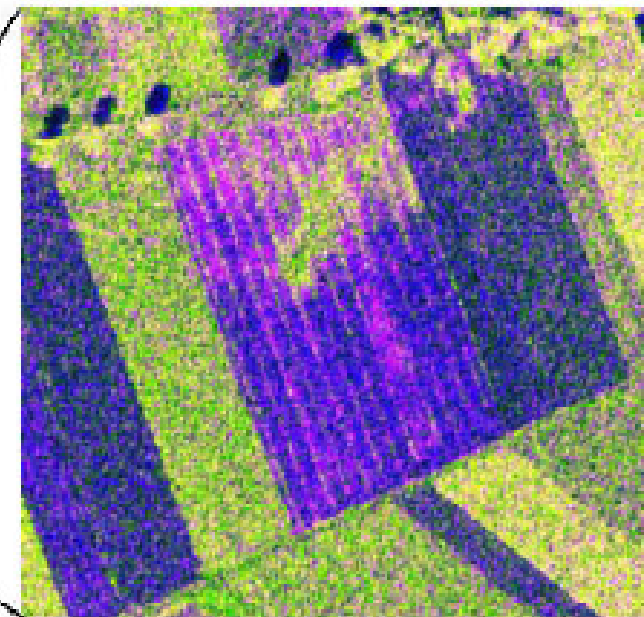


Pol-InSAR, razpoznavanje poljščin

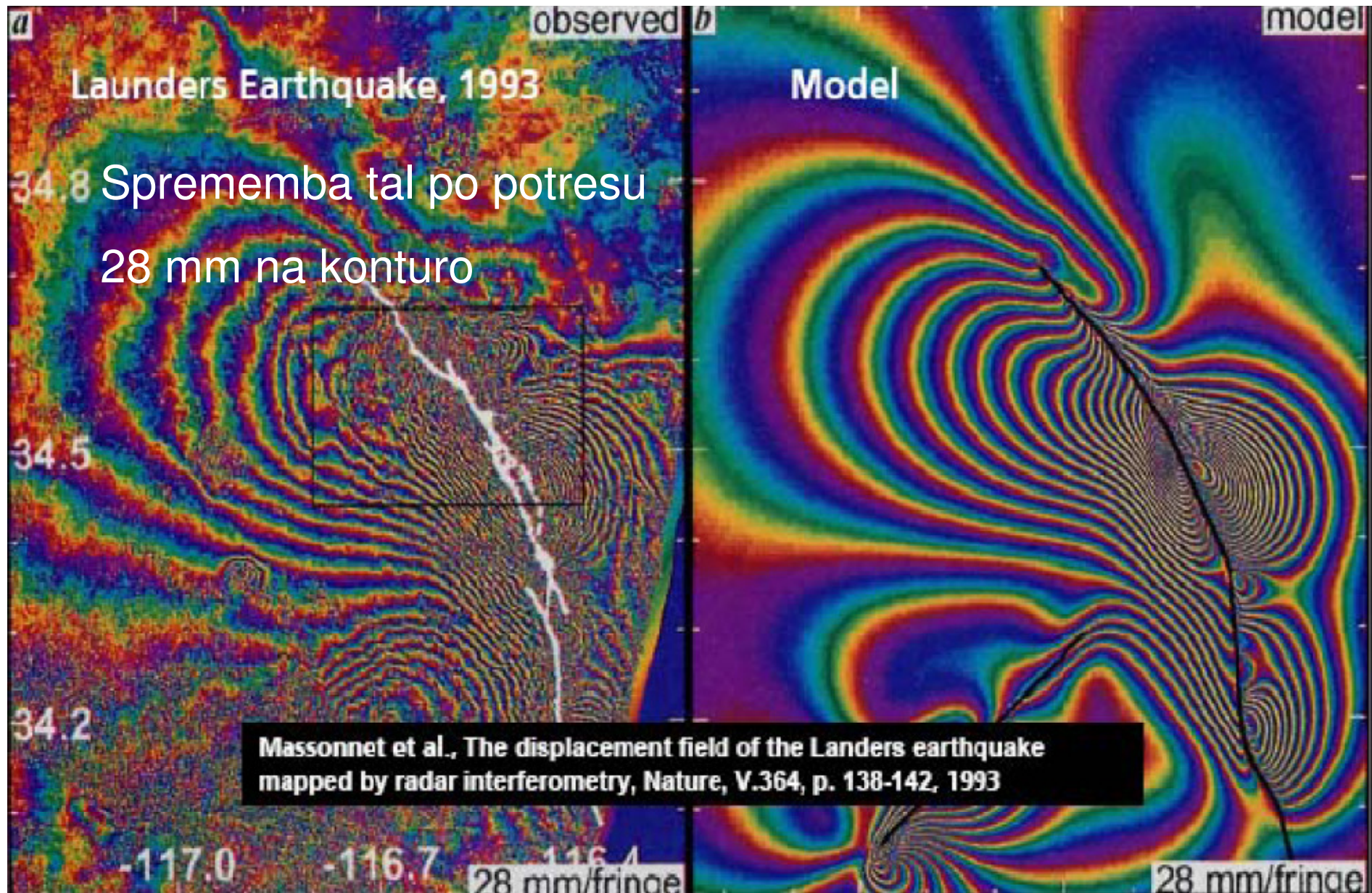


| | | |
|--------|---------|----------|
| Potato | Fruit | Oats |
| Beet | Barley | Onions |
| Wheat | Beans | Peas |
| Maize | Flax | Rapeseed |
| Grass | Lucerne | |

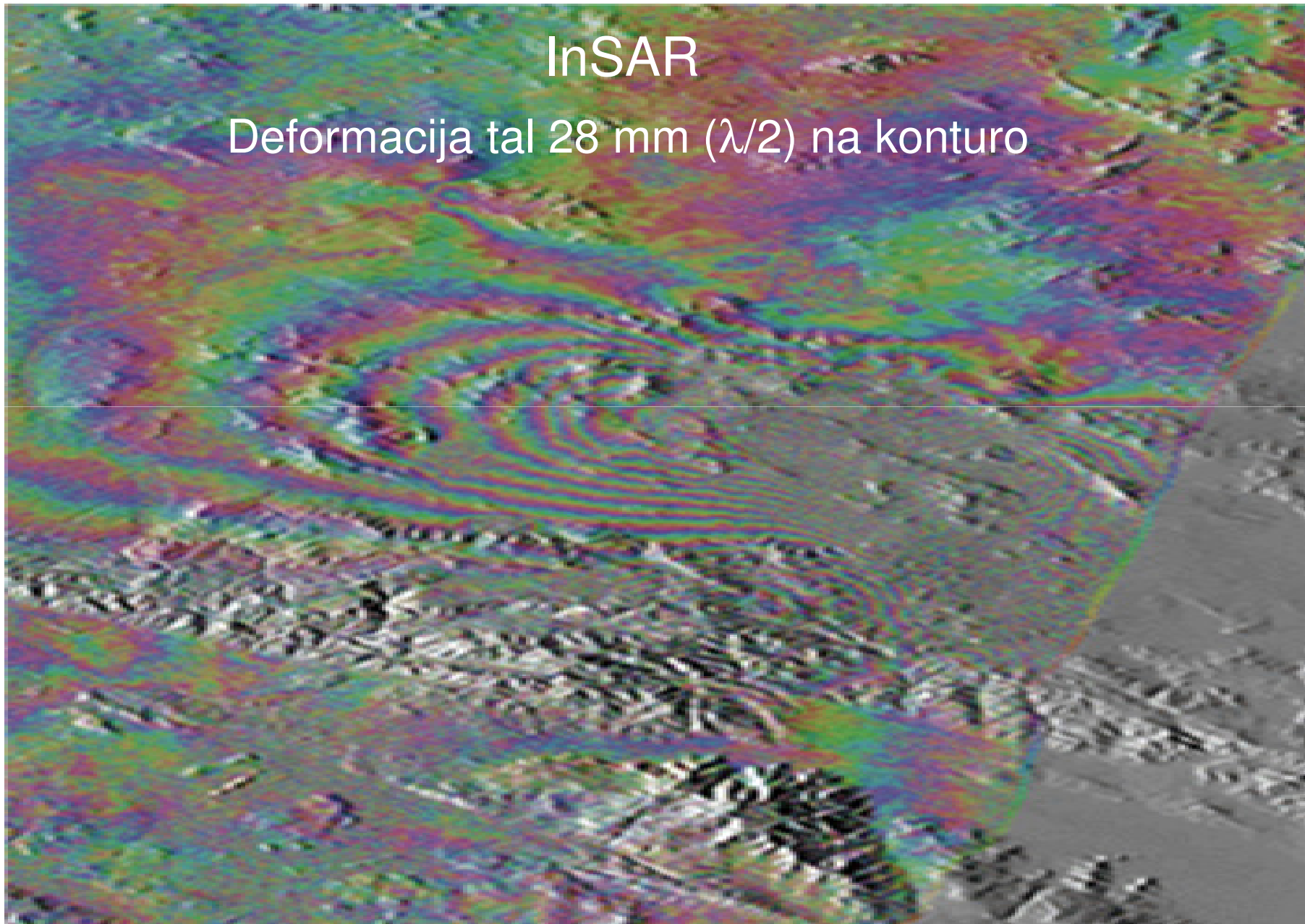
Razpurnavanje poljščin, ocena pridelka⁶³



Diferencialni InSAR

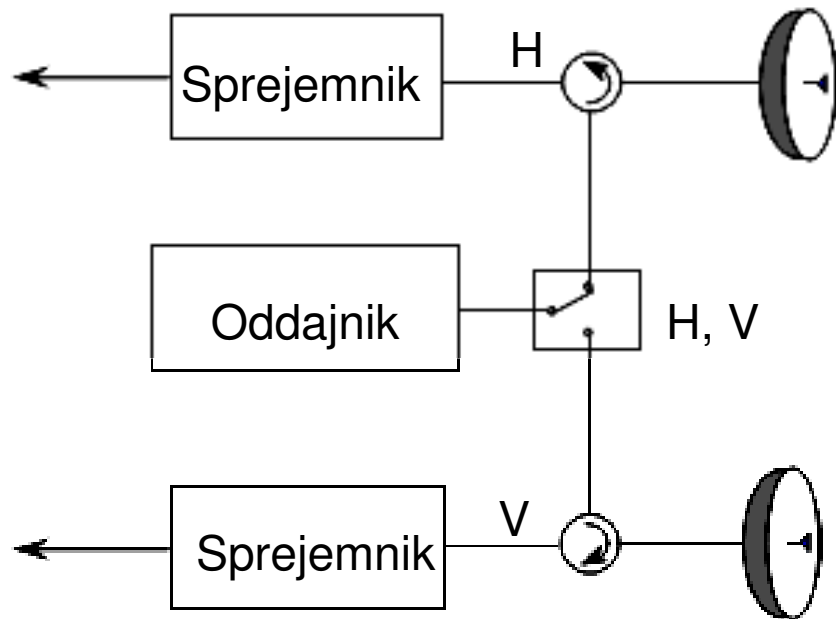


Meritev deformacije tal

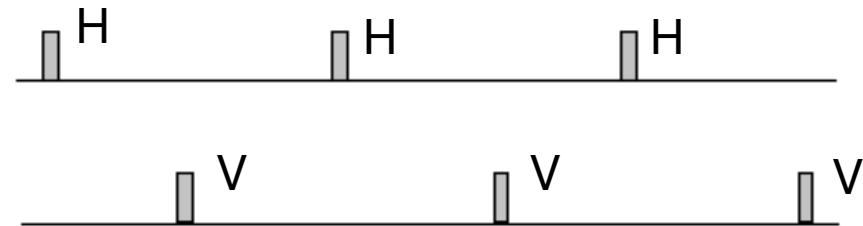


Štiripolarizacijski Pol-InSAR

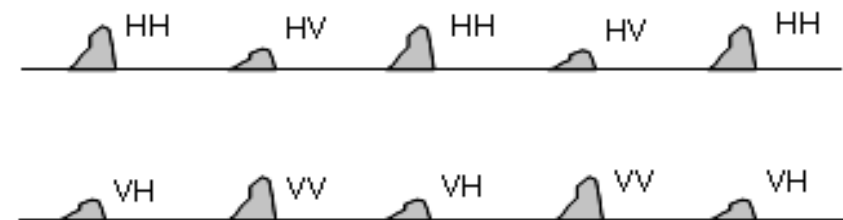
66



Oddajani signal: H in V



Sprejemani signal: H in V



Načini:

- Enopolarizacijski HH ali VV ali HV
- Dvopolarizacijski HH, VV ali HV
- Quad HH, VV, HV, VH

Sistemi:

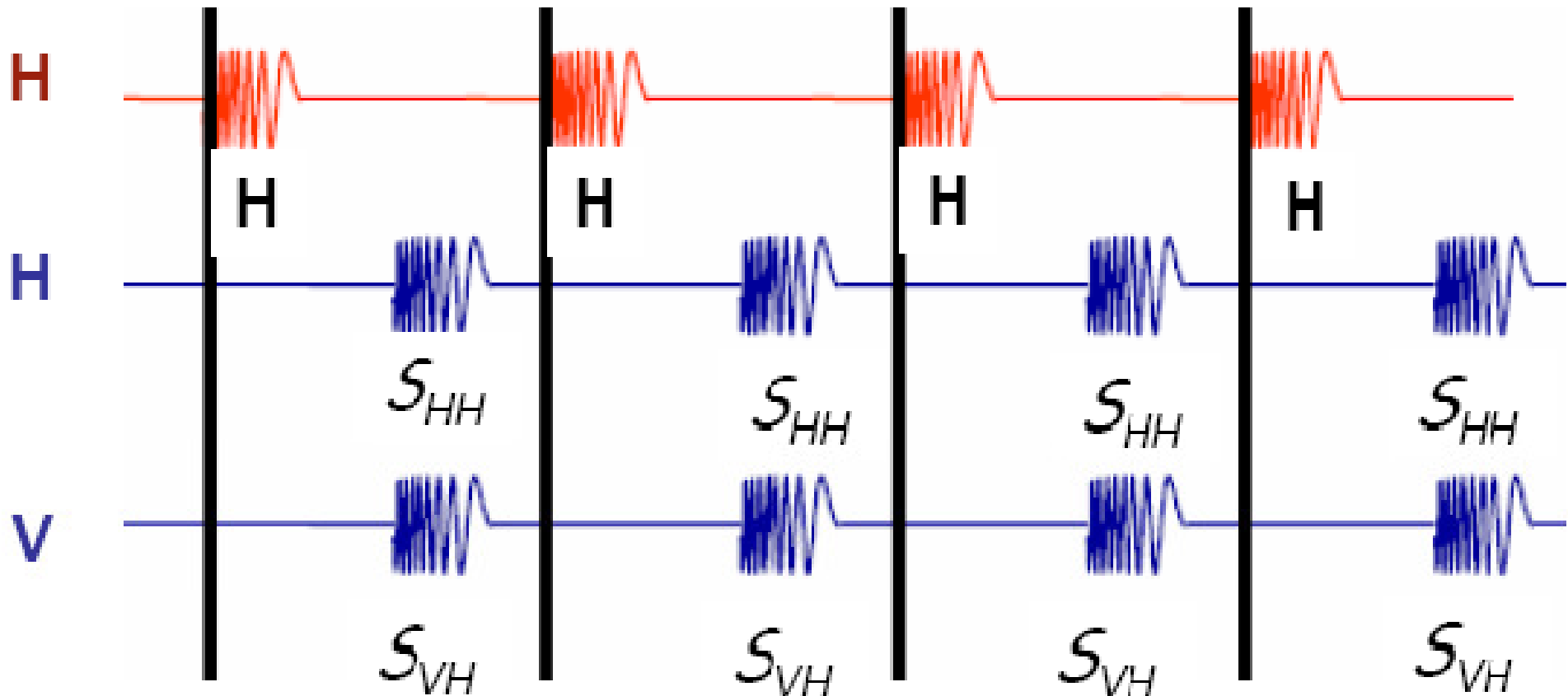
- Operativni; navadno 1 polarizacija (HH ali VV)
- Raziskovalni; 4 polarizacije (Quad)

Primer: oddaja H - sprejem na H in V ⁶⁷

H ... Oddaja na horizontalni polarizaciji H

HH ... Oddaja na horizontalni polarizaciji H in sprejem na horizontalni polarizaciji H

VH ... Oddaja na horizontalni polarizaciji H in sprejem na vertikalni polarizaciji V

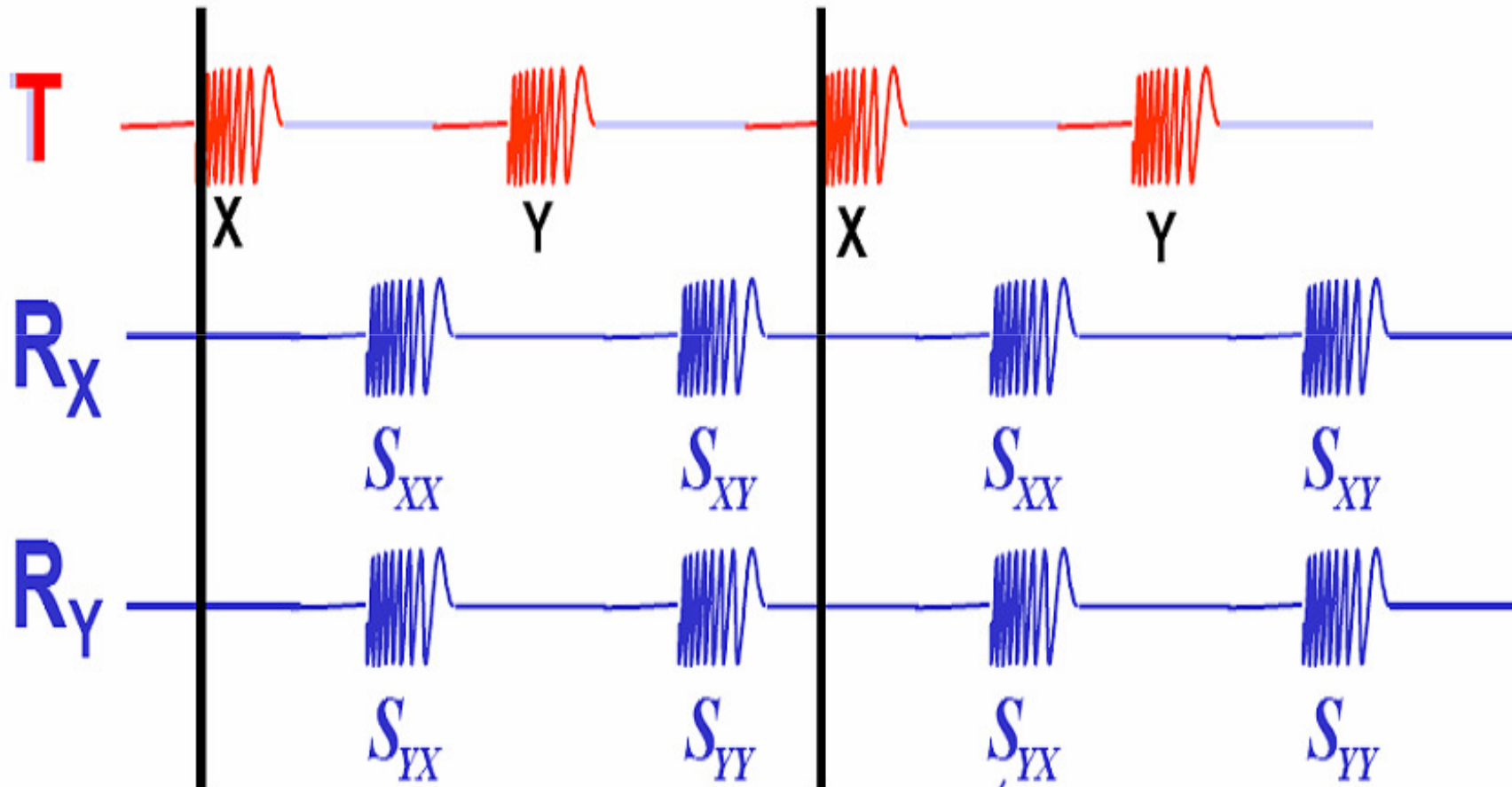


$$S_{HV} = S_{VH}$$

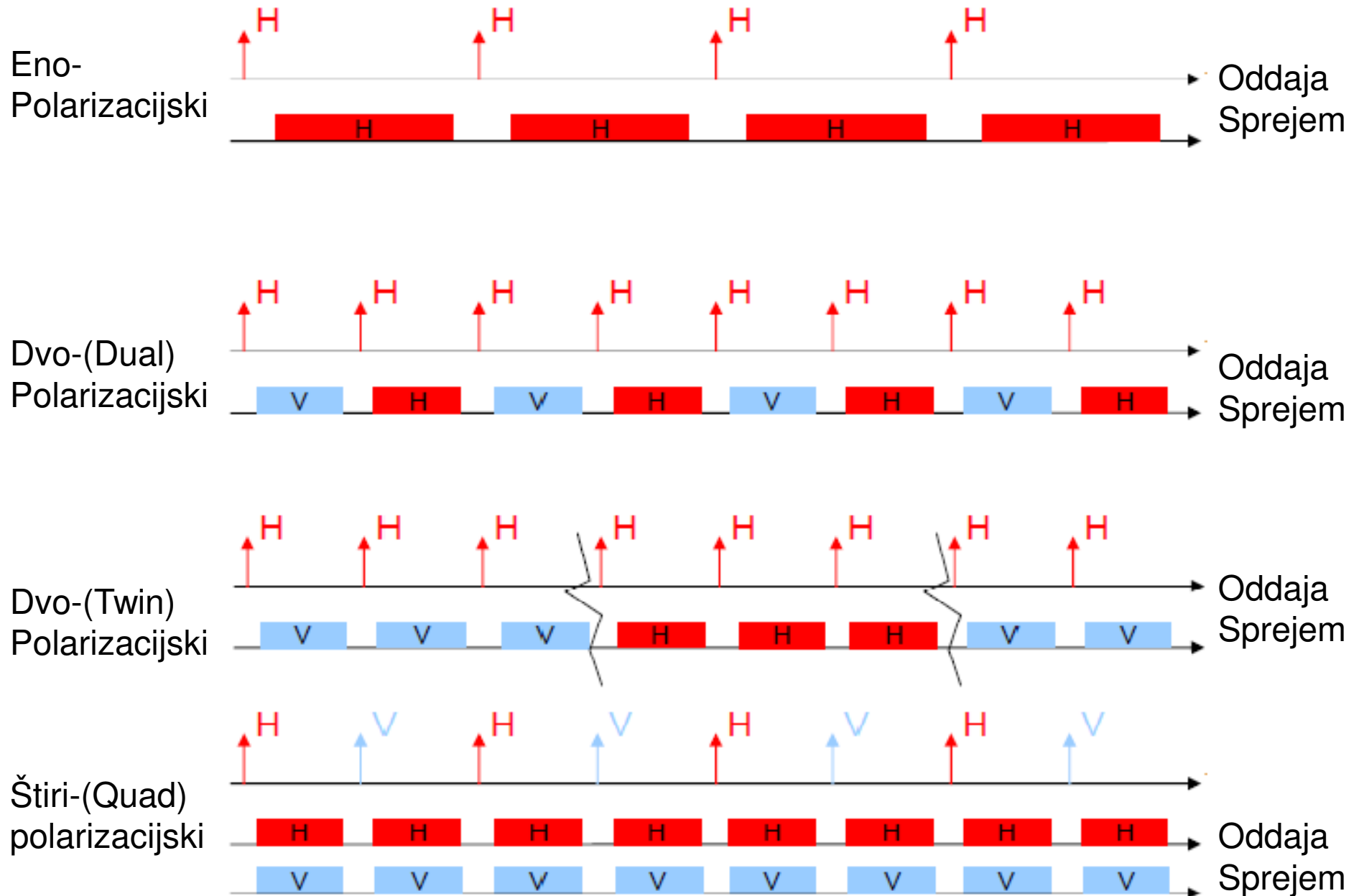
Primer: oddaja izmenično na H in V

T ... Oddaja izmenično na X in Y polarizaciji

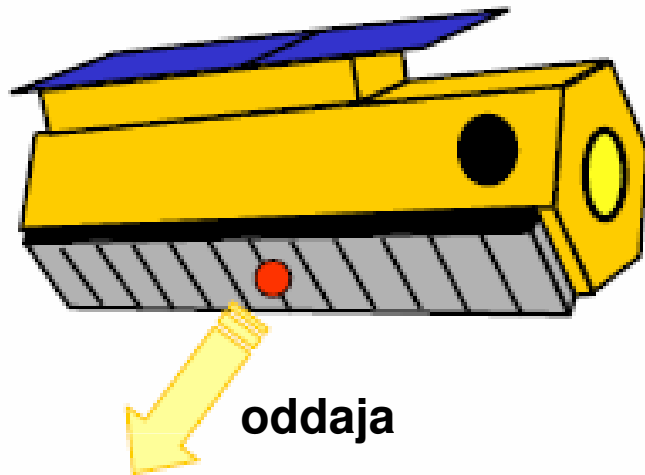
R_x, R_y ... Sprejem na X in Y polarizaciji



Polarimetrični sistemi

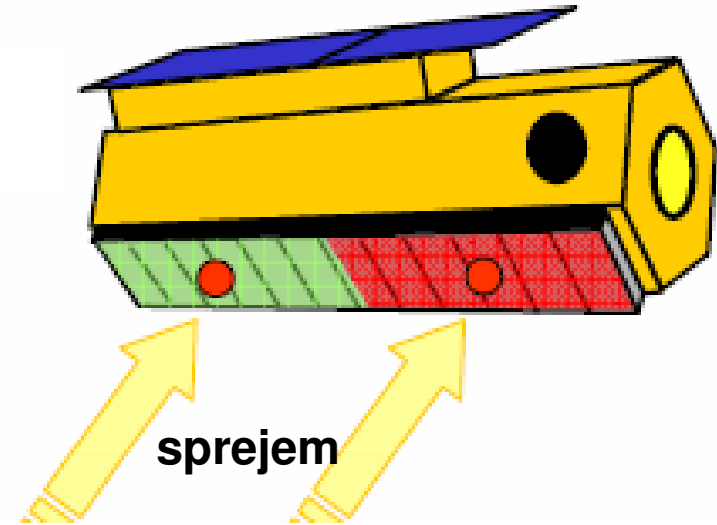


TeraSAR polarizaija TX in RX



oddaja

Oddaja z izmenično polaizacijo



sprejem

dvopolarizacijski sprejem

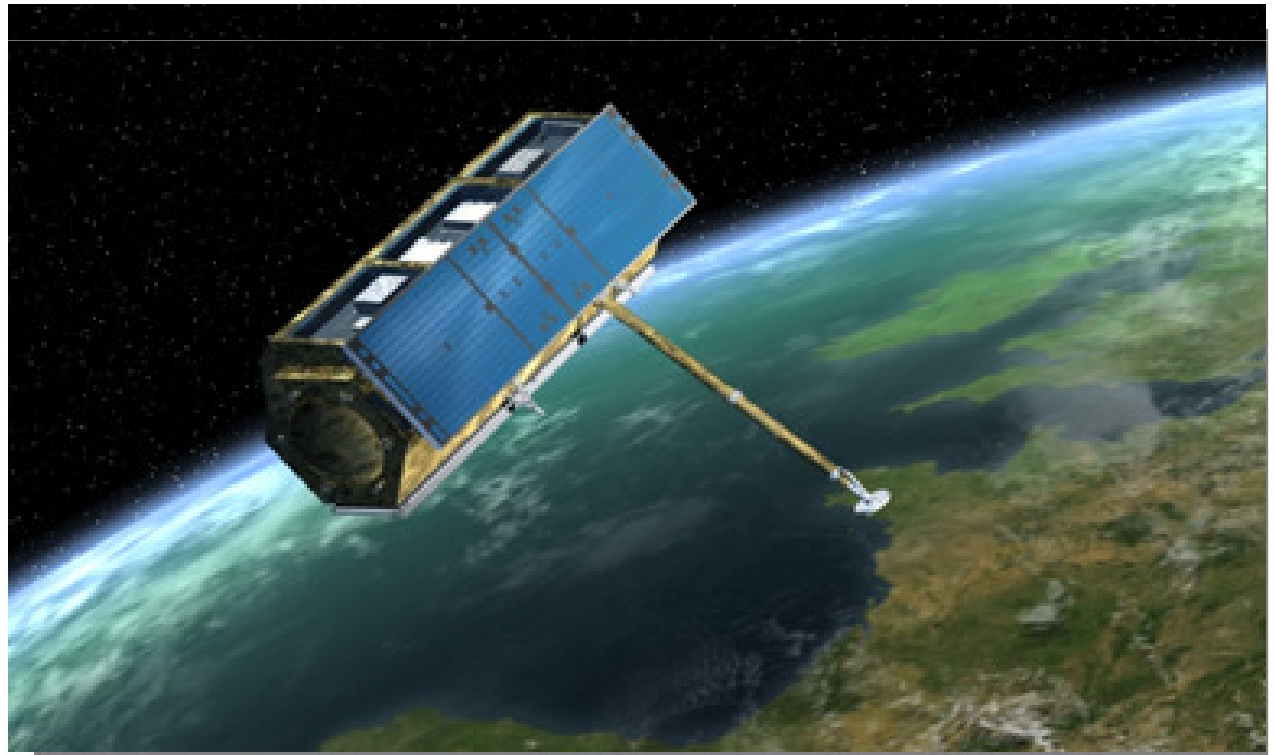
| | | | | | |
|-------------------|----|----|----|----|-----|
| TX: | V | H | V | H | ... |
| RX ₁ : | V | V | V | V | ... |
| RX ₂ : | H | H | H | H | ... |
| CH ₁ : | VV | HV | VV | HV | ... |
| CH ₂ : | VH | HH | VH | HH | ... |

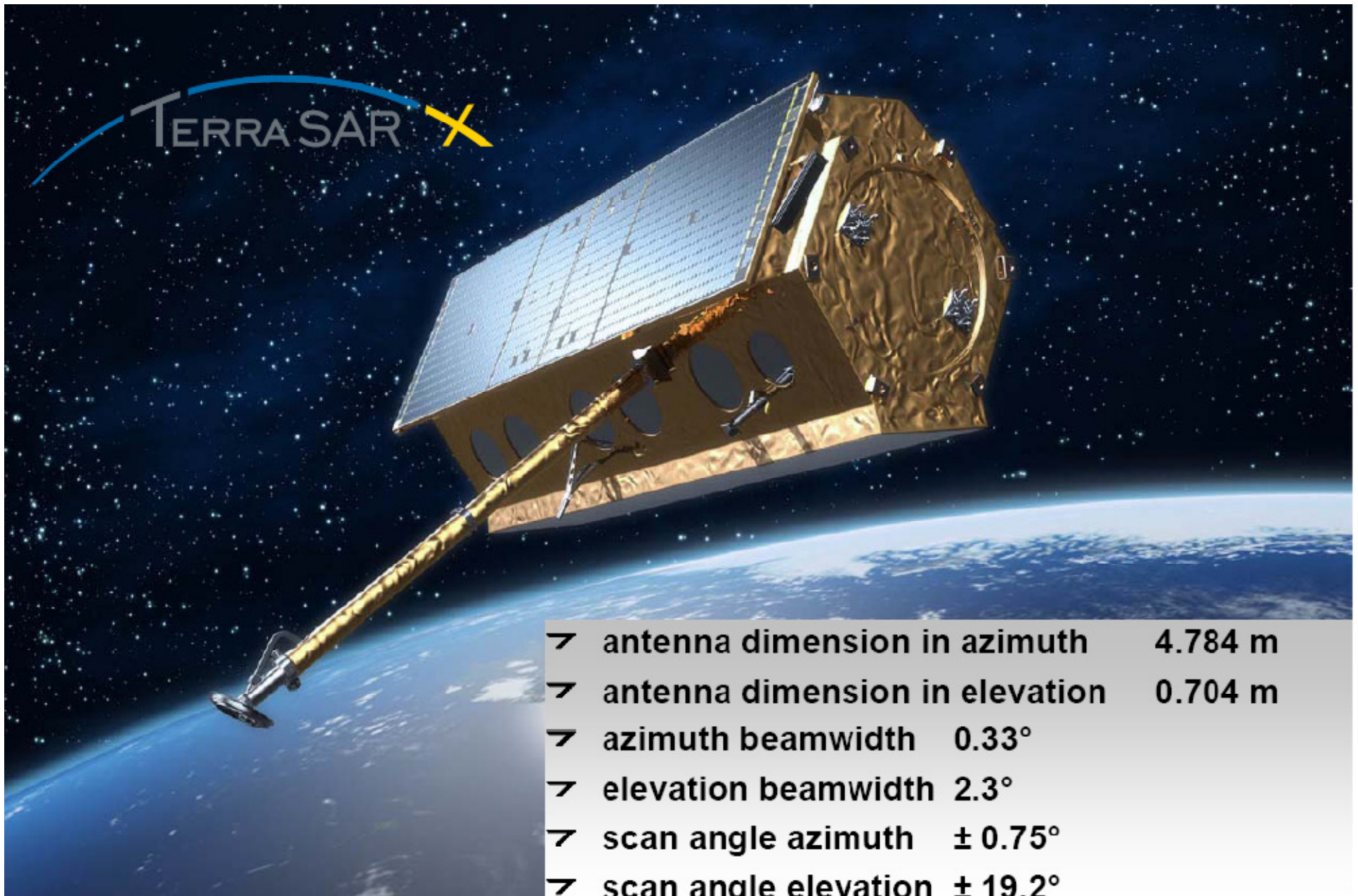
TerraSAR - X

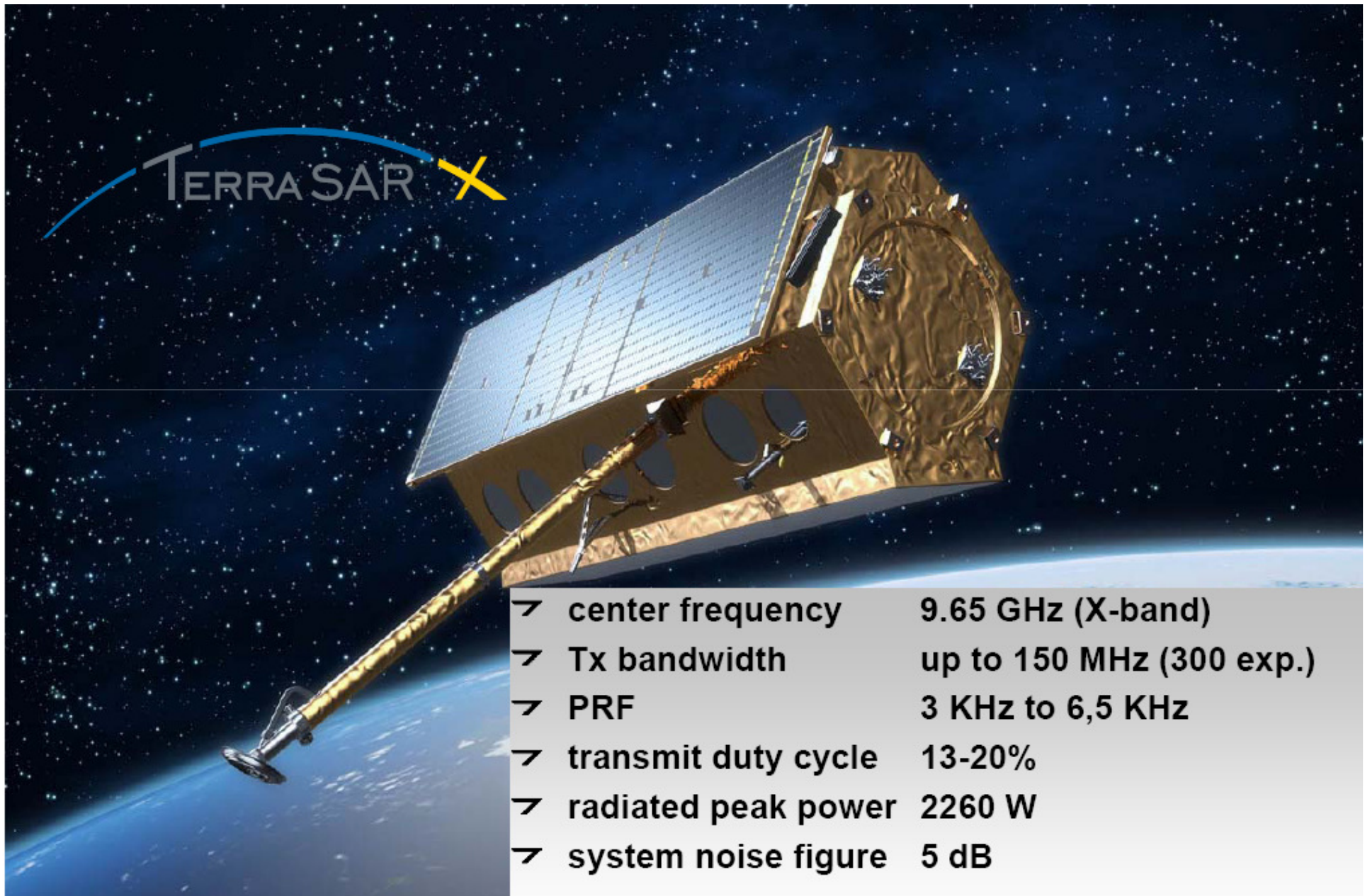
- Vtiritev: 2007
- Predvidena doba delovanja: 5 let
- 1. **Podatki o načinu delovanja:**
 - pasovno, širina 30 km, resolucija 3 m
 - skaniranje, širina 100 km, resolucija 16 m
 - točkovno: območje
5 x 10 km
 - resolucija 1 m
 - sprejem:
dvopolarizacijski
 - perioda ponavljanja:
11 dni
 - Levi in desni pas

2. Podatki o tirnici:

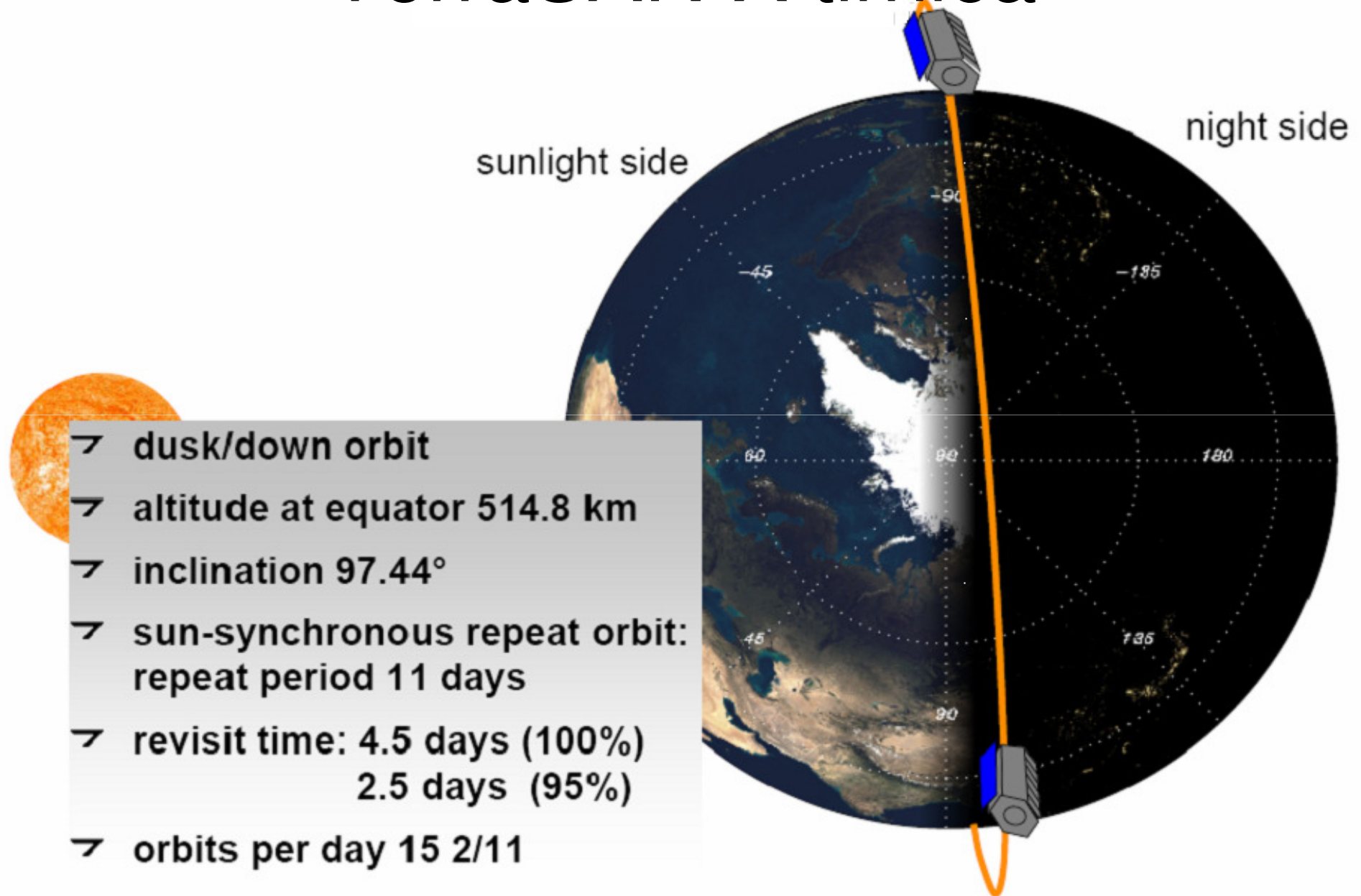
- Solarno stacionarna orbita:
 - Naklon $97,4^{\circ}$
 - Obhodna doba 95 min.
 - Višina 414 km

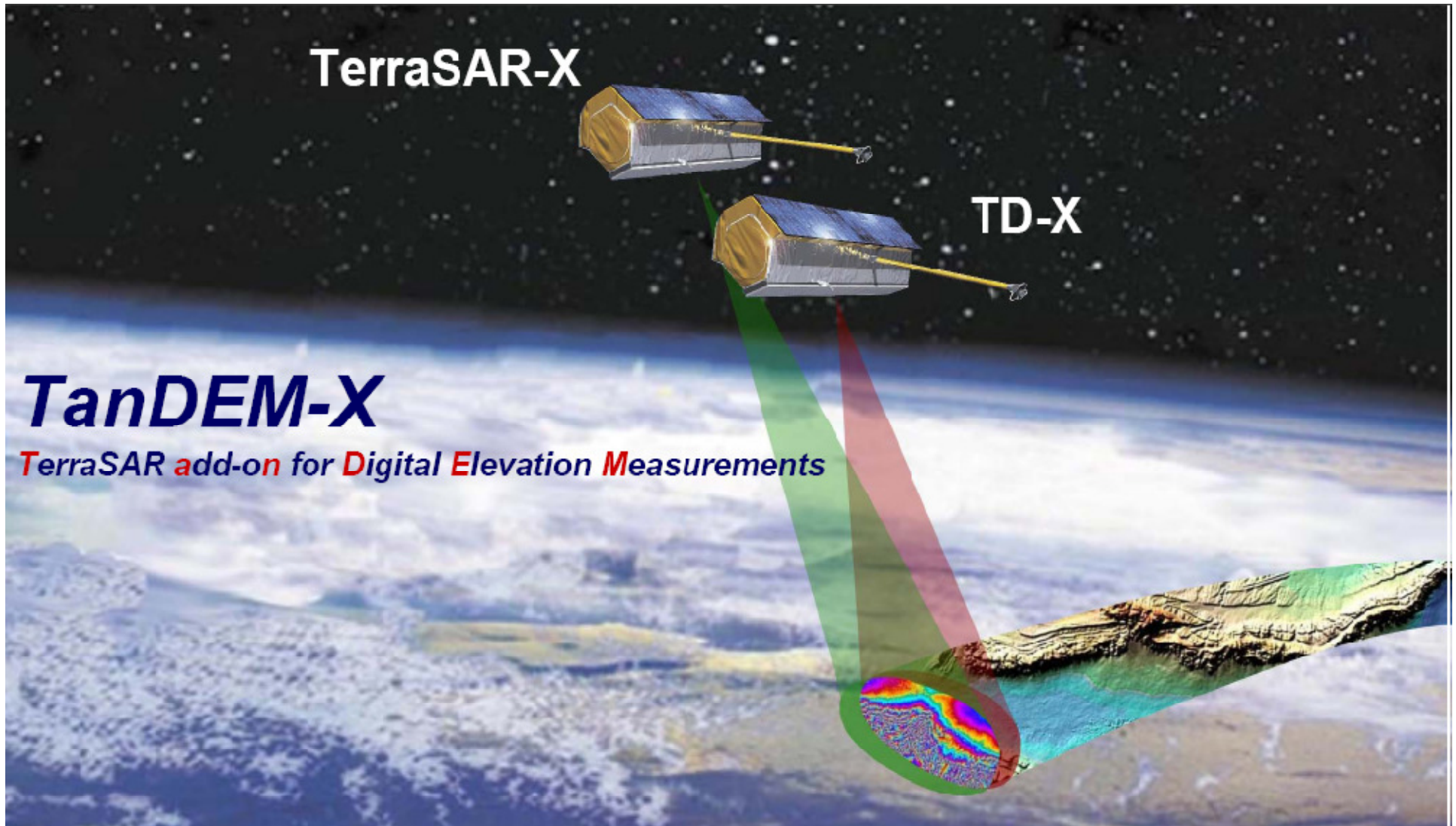




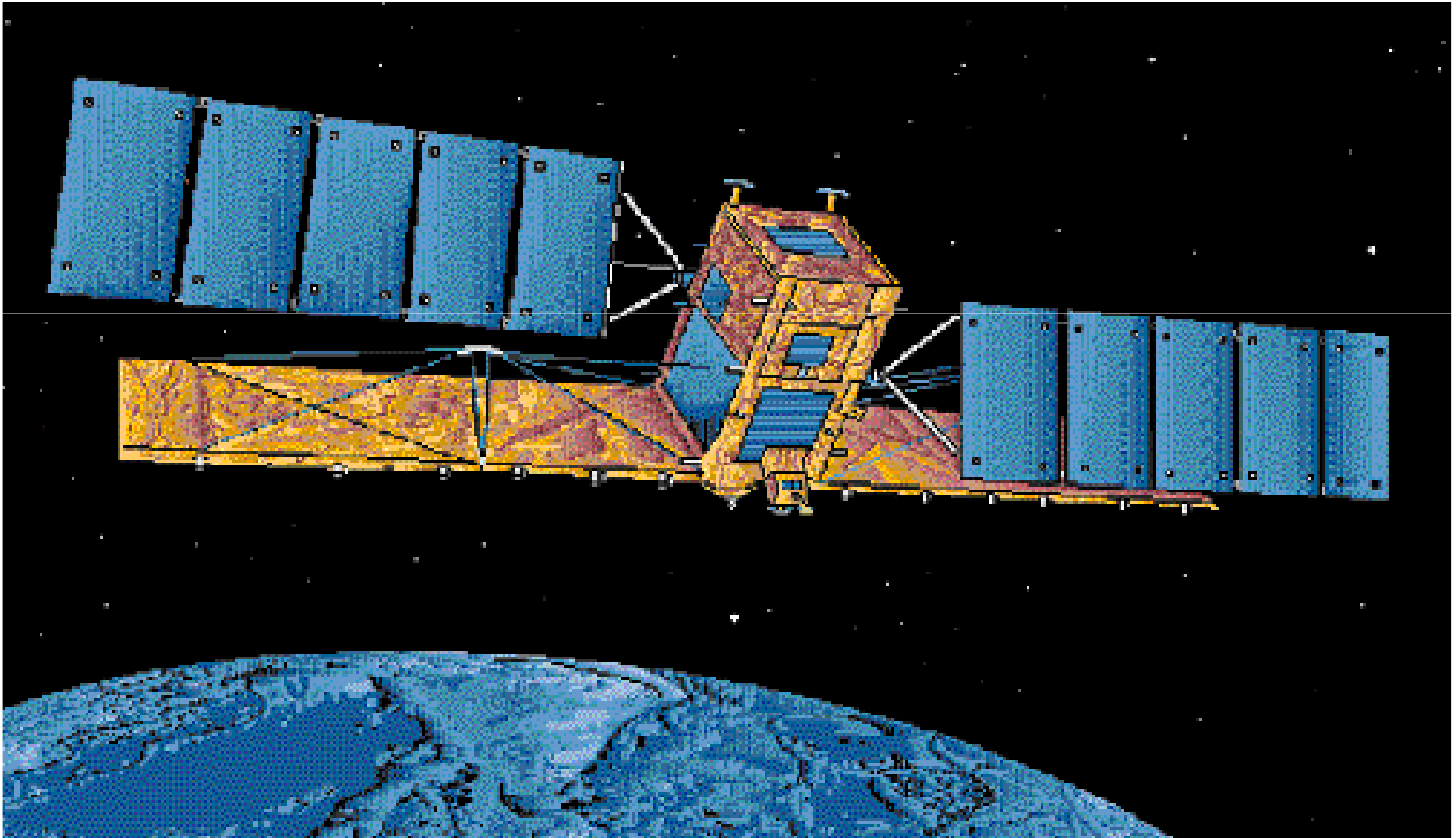


TerraSAR-X tirnica





RadarSAT 1



RADARSAT-2

Helio-sinhrona orbita, višina 798 km

Polarizacija:

1. HH ali VV ali HV ali VH
2. HH in HV ali VV in VH
3. HH in VV in HV in VH

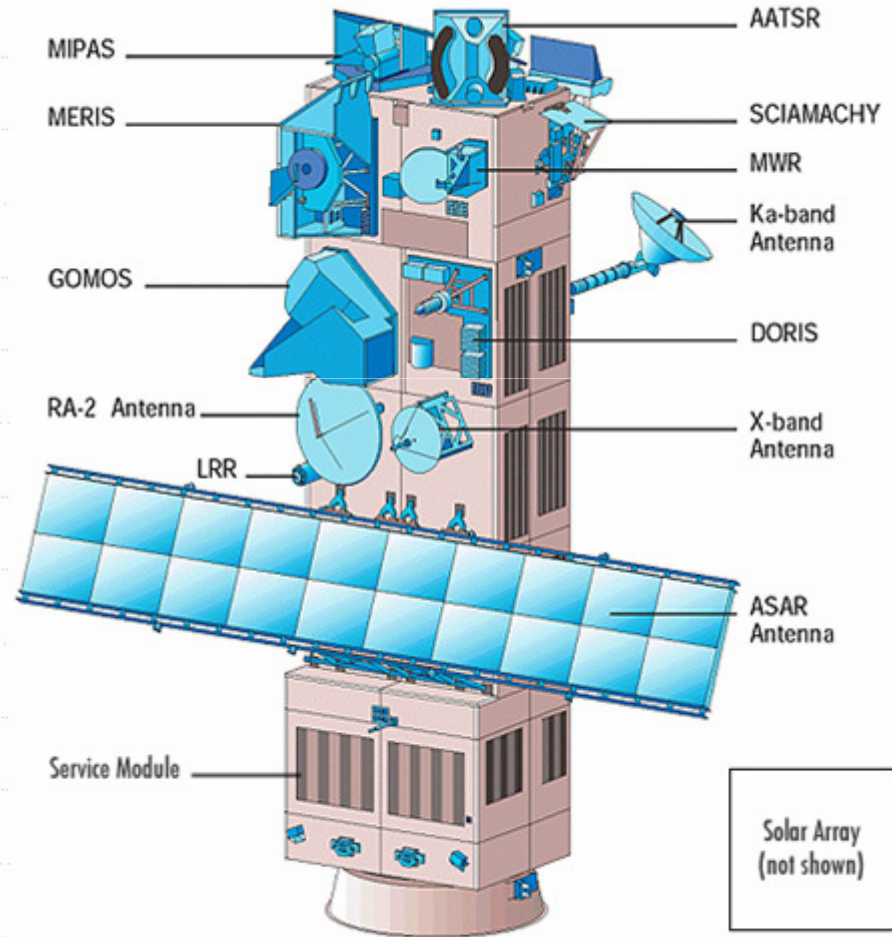
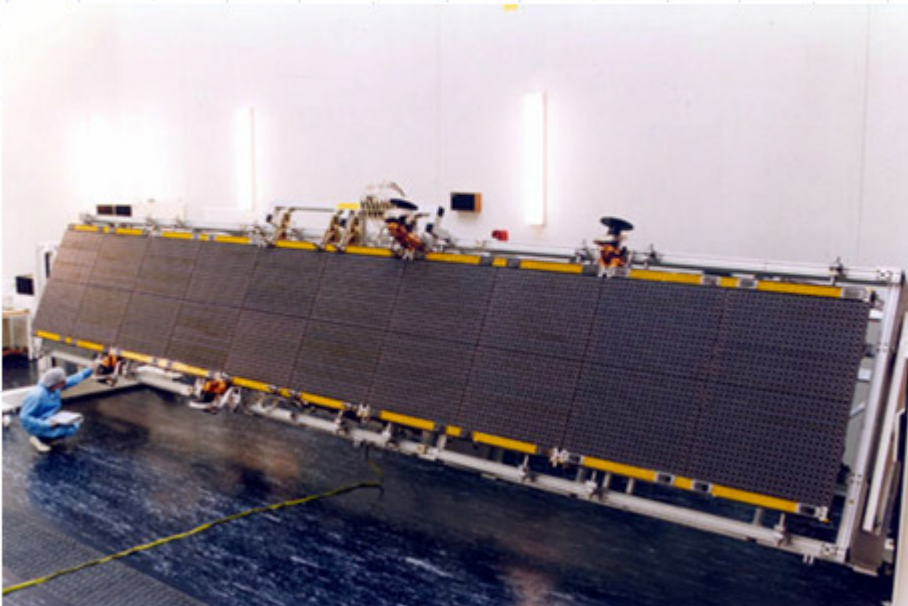


Envisat

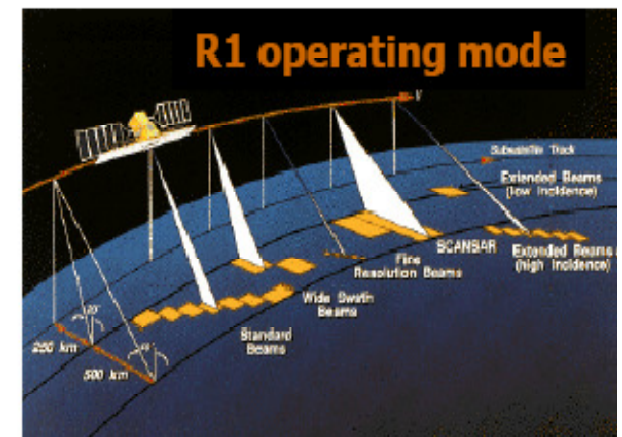
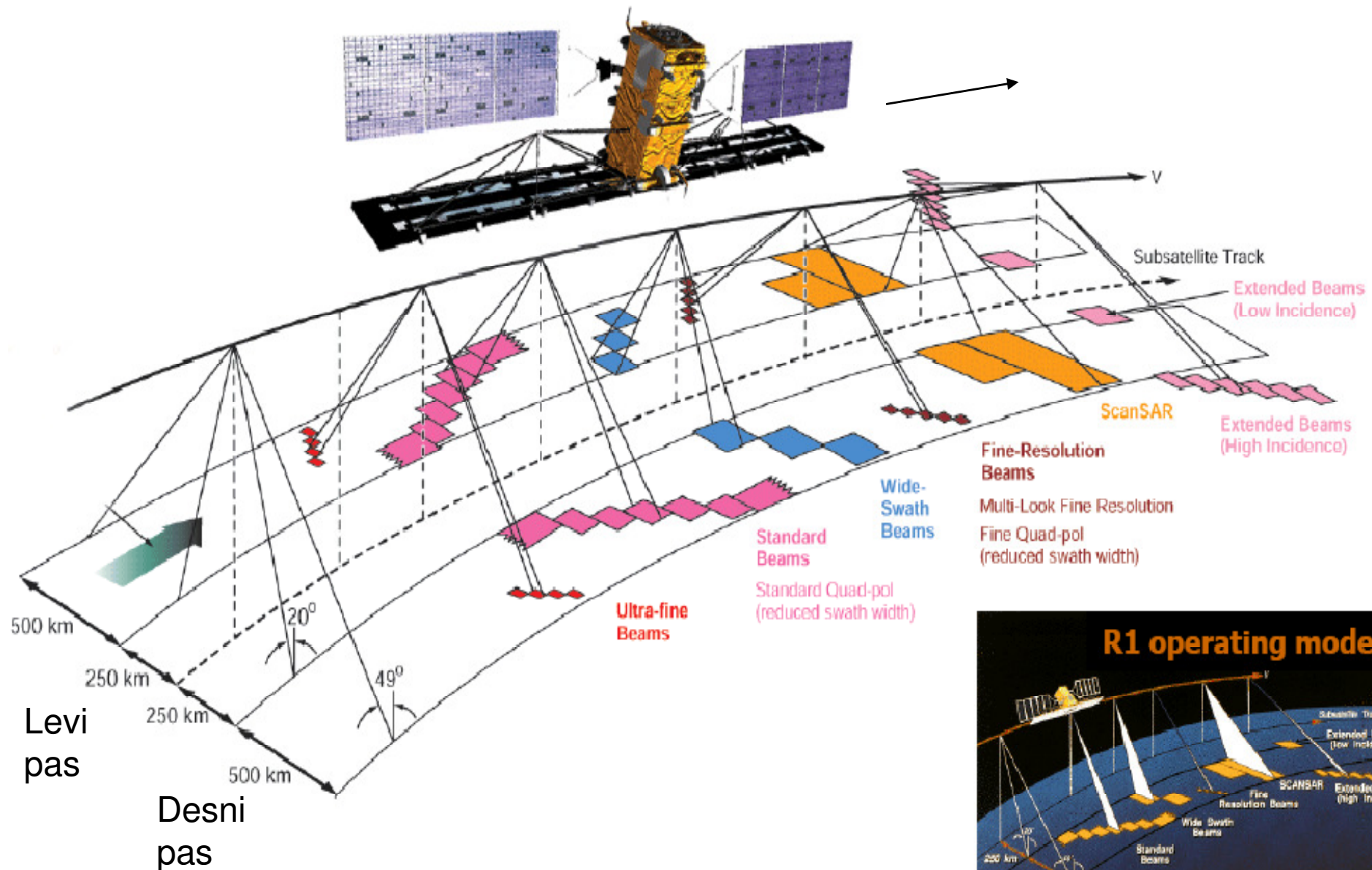
Launched 2002.2.28

C-band, Multpol, multi-mode

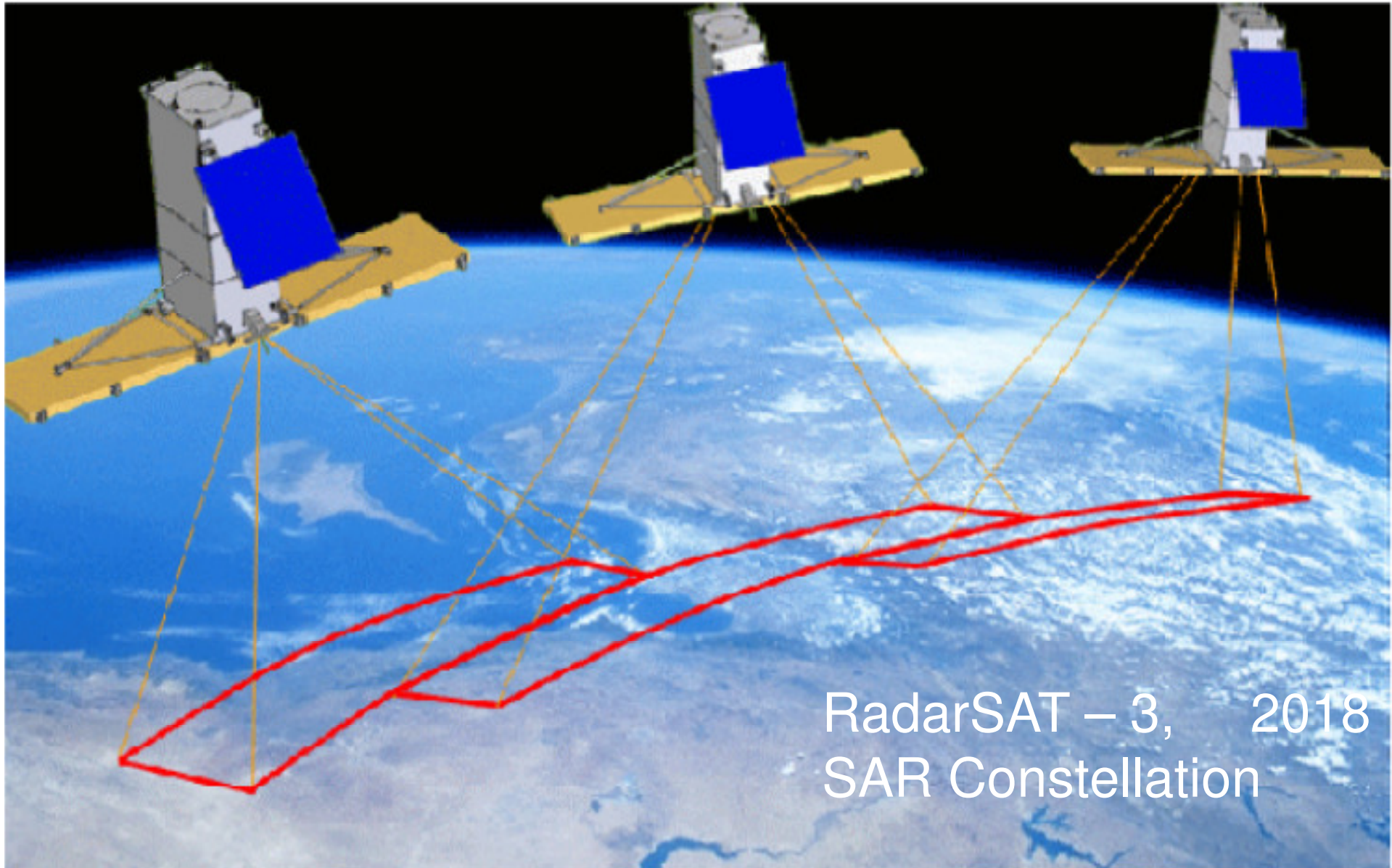
Data : Envisat Announcement of Opportunity



RadarSAT-2 – načini delovanja



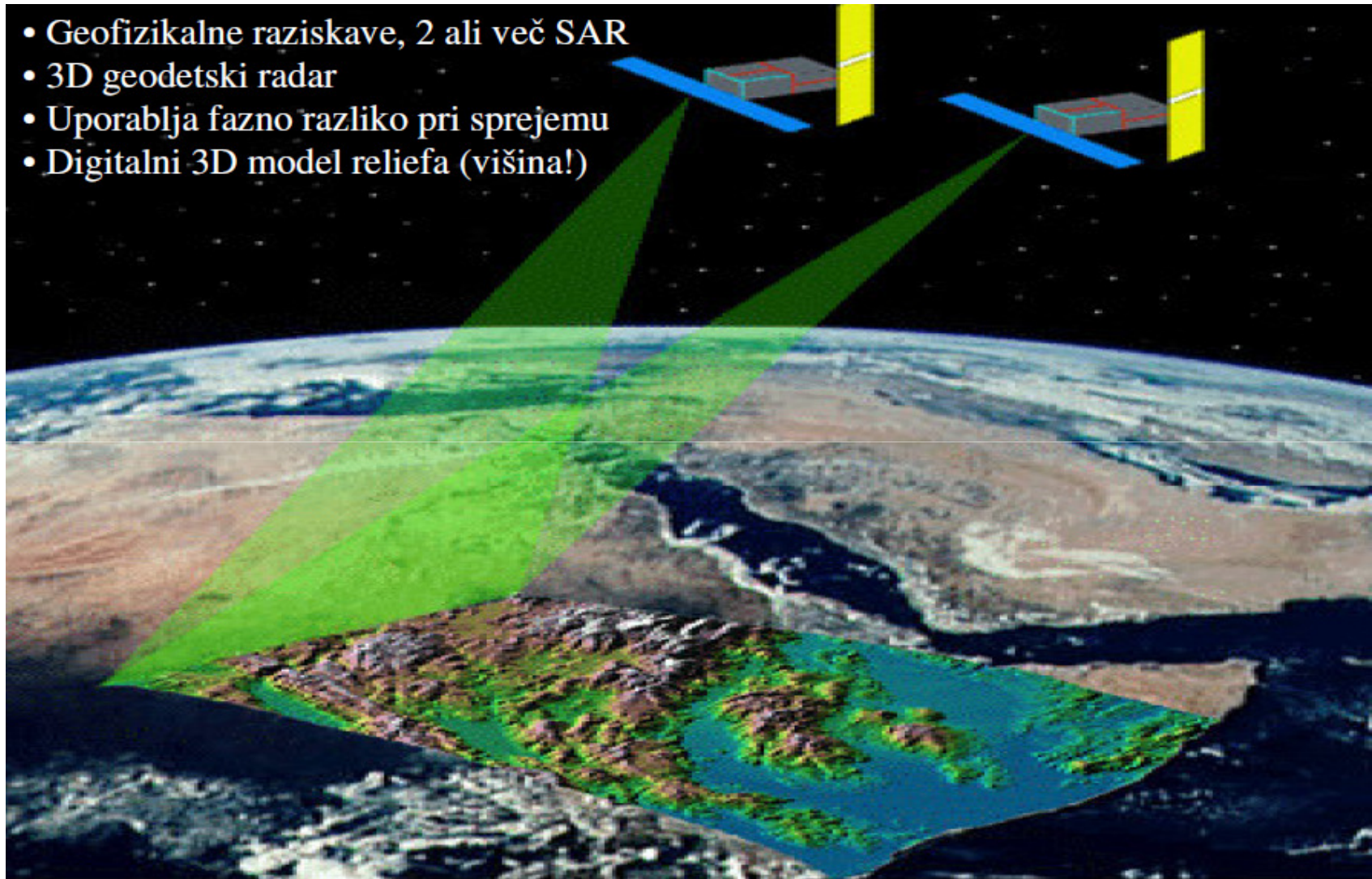
Projekt RadarSAT-3, konstelacija



Dvosatelitski enopreletni InSAR

81

- Geofizikalne raziskave, 2 ali več SAR
- 3D geodetski radar
- Uporablja fazno razliko pri sprejemu
- Digitalni 3D model reliefa (višina!)



Primer polarizacijskega odziva

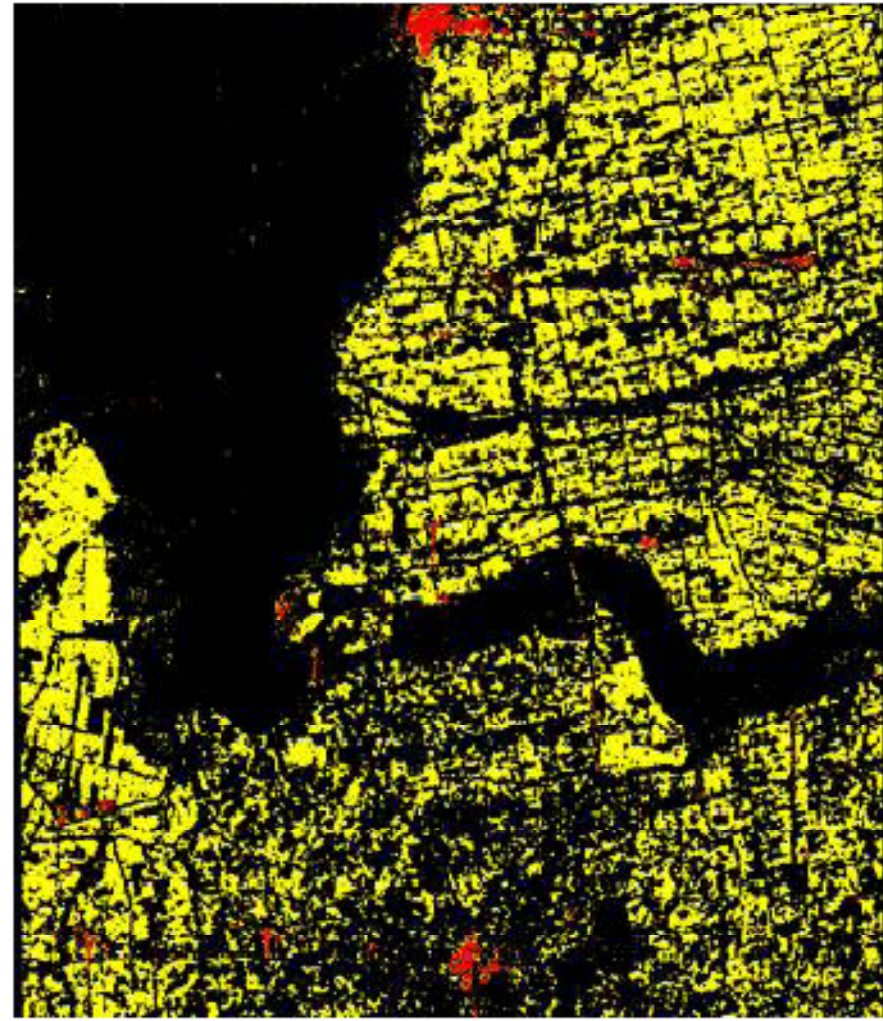
82

September 6th, 2004

Hongze area

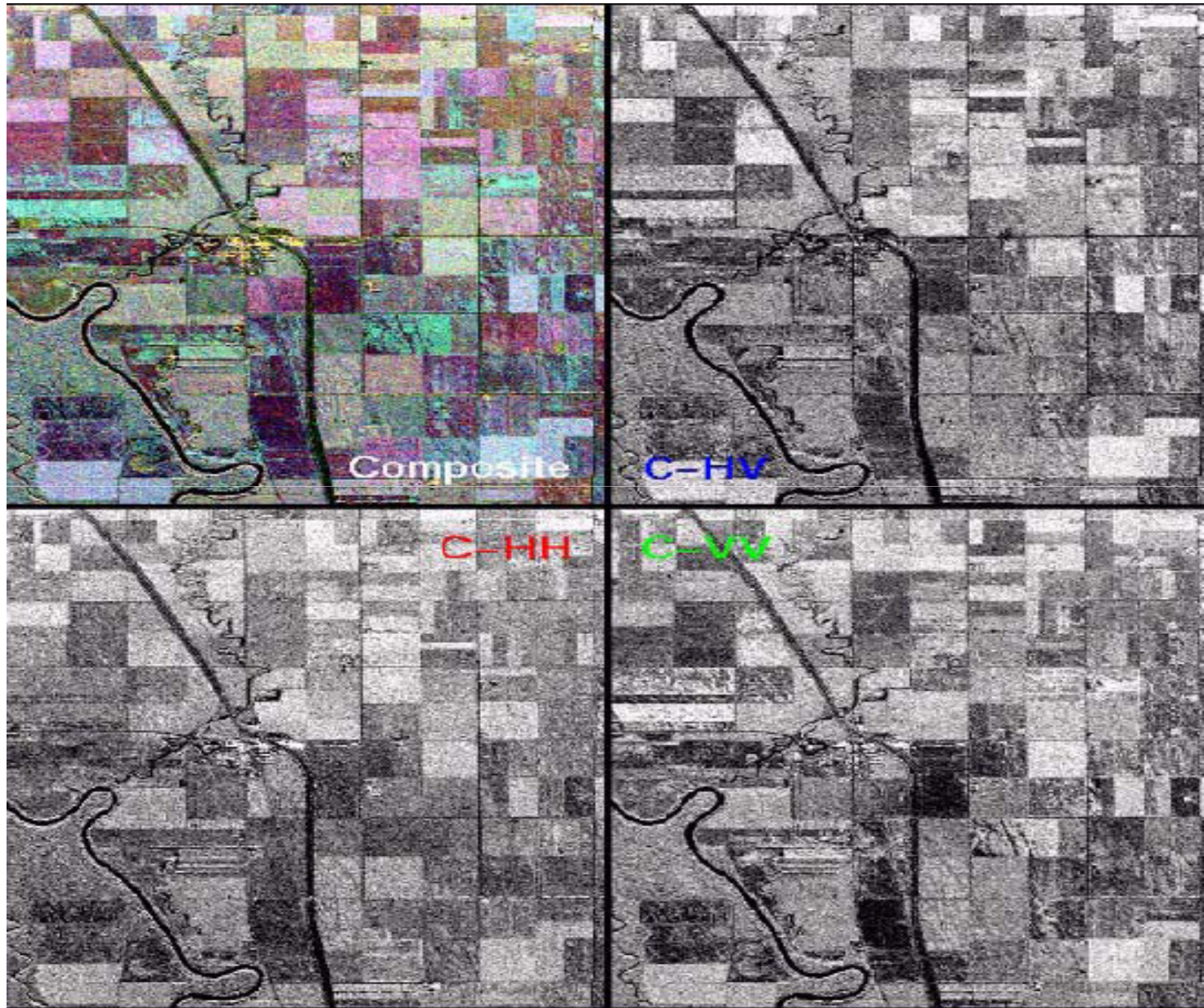


Magenta=HH, Green=VV

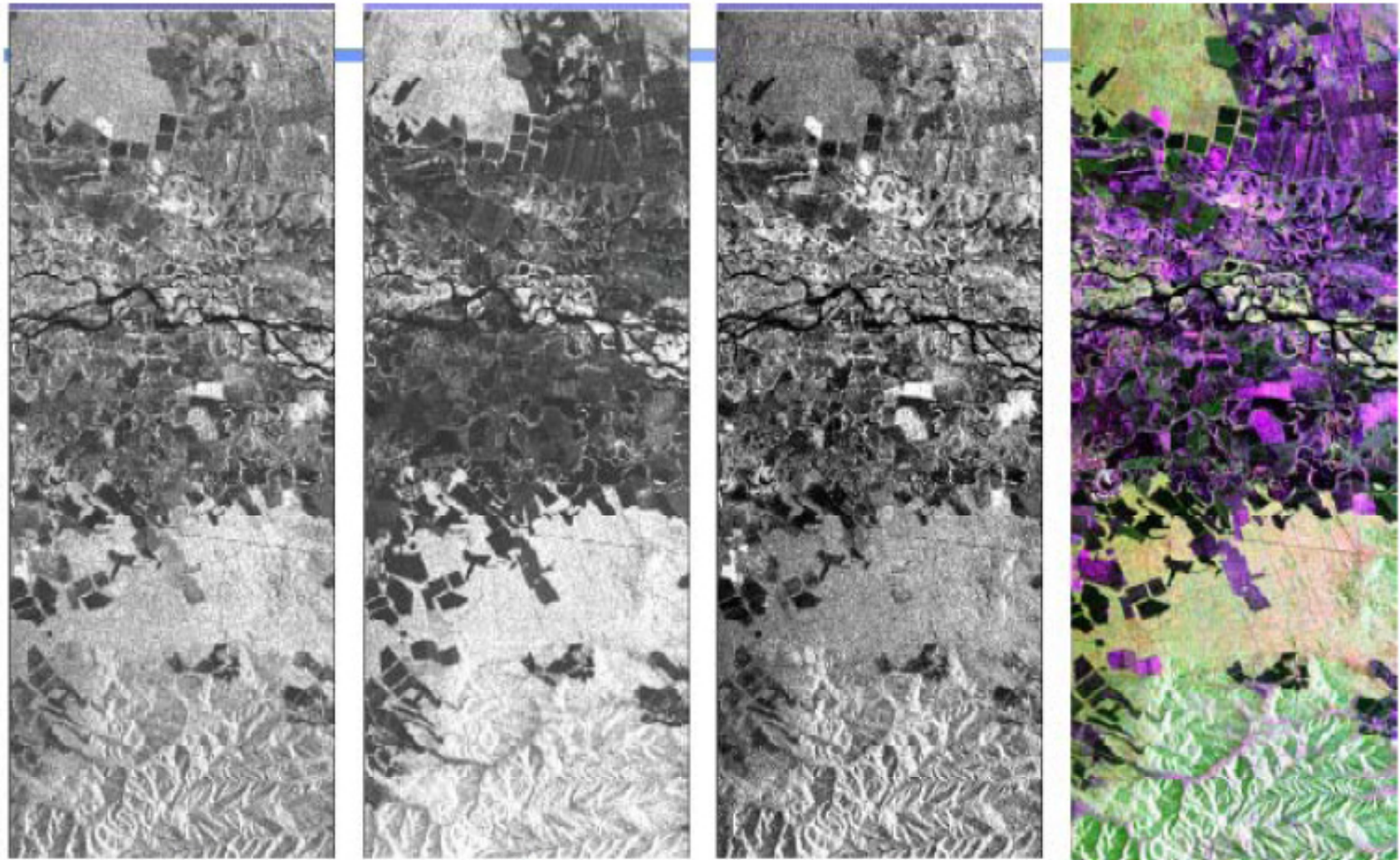


yellow=rice, red=urban, black=other

Polarimetrična slika tal



Valovno področje C, polarizacija oddaja sprejem HV, HH, VV



HH

HV

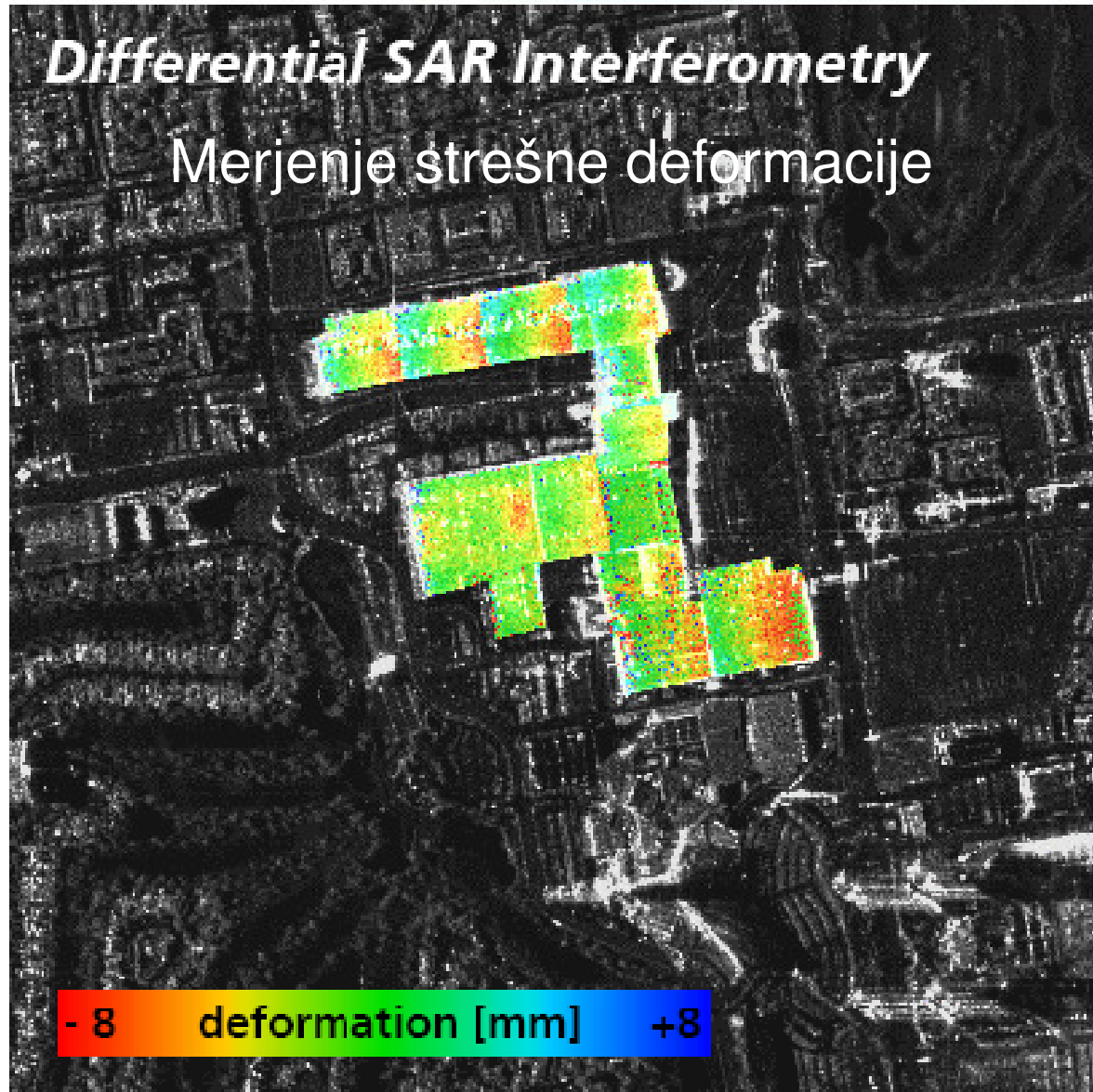
VV



SIR-C images, L-band 24°, Ulan-Ude, Russia, 1994

Primer diferenčne interferometrije

85

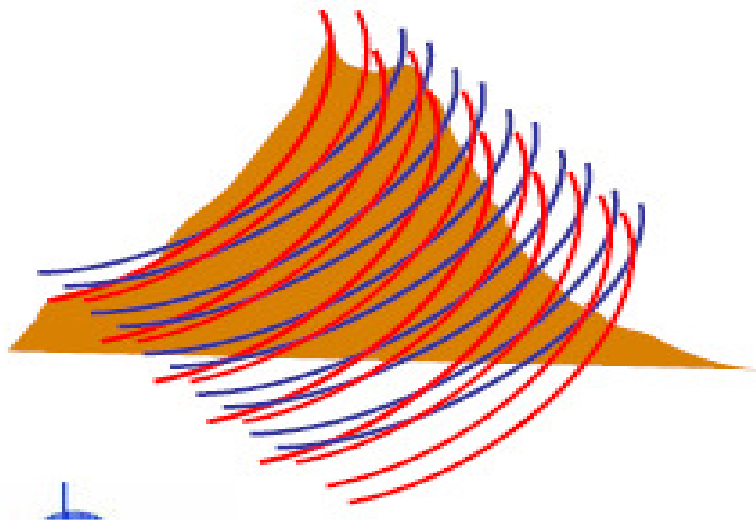
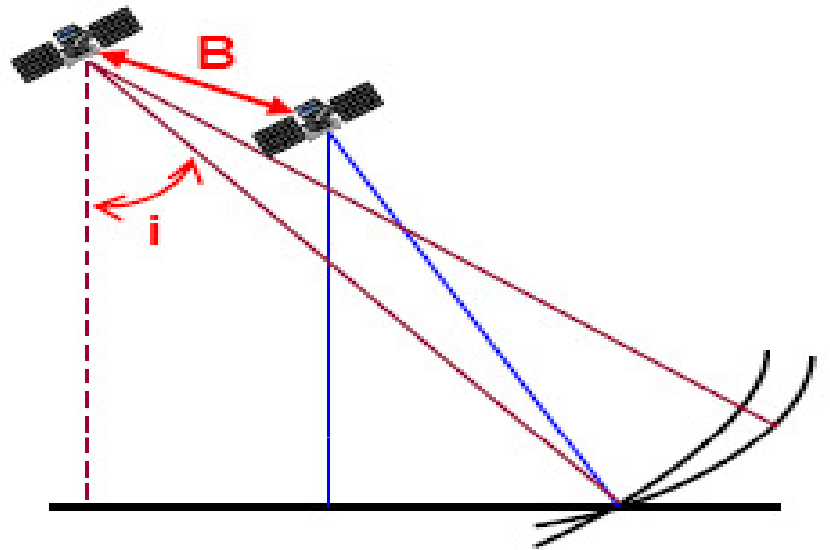


Las Vegas Convention Center

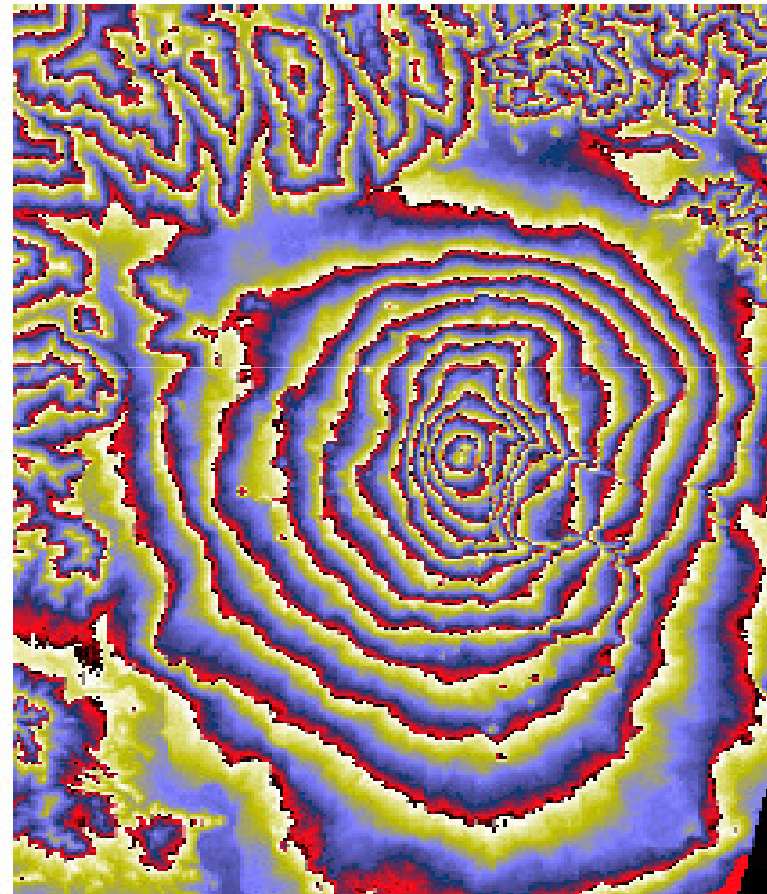
Zaznava spremembe stanja na terenu⁸⁶



Tandem interferometrija, primer Etna ⁸⁷



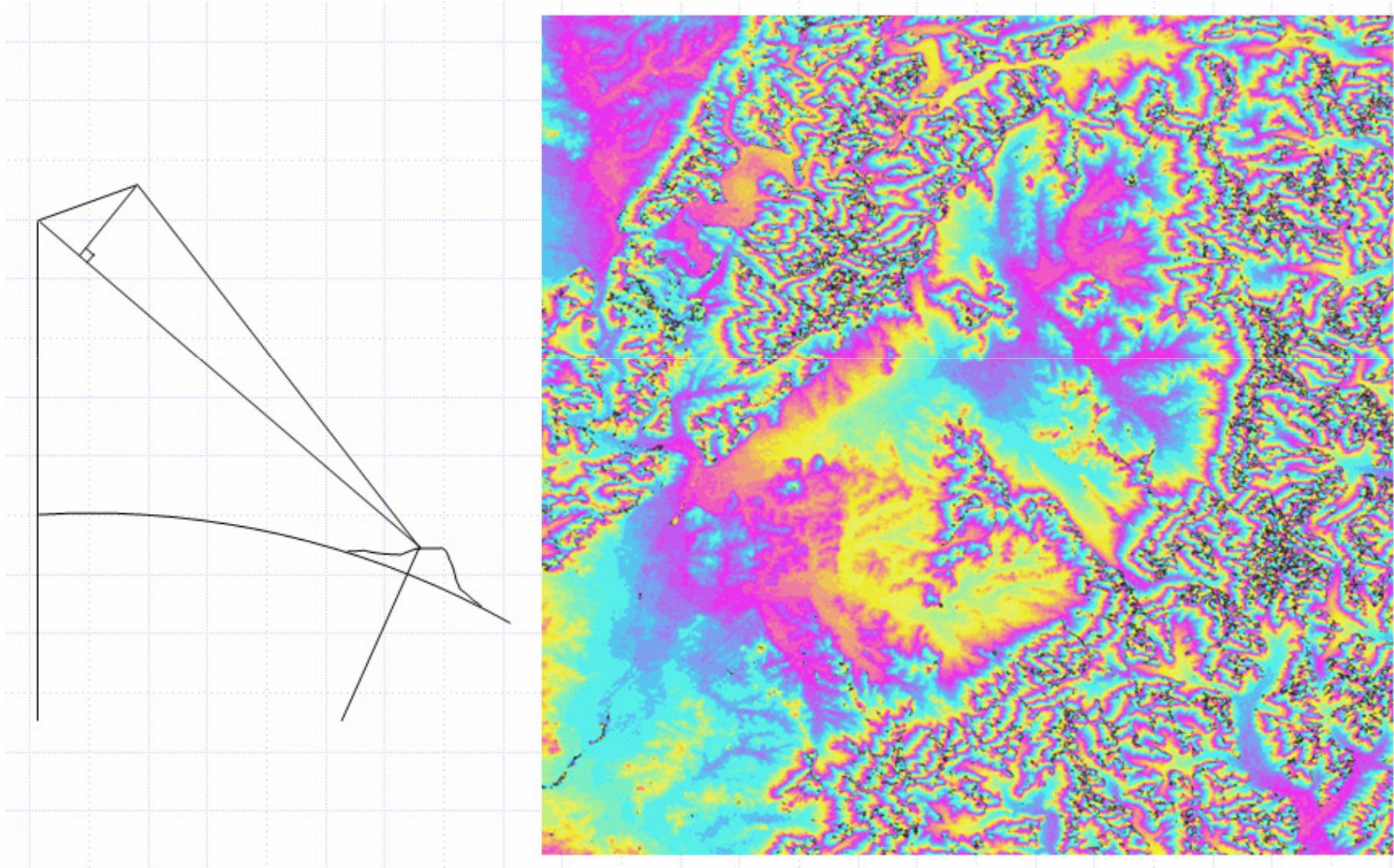
Relief



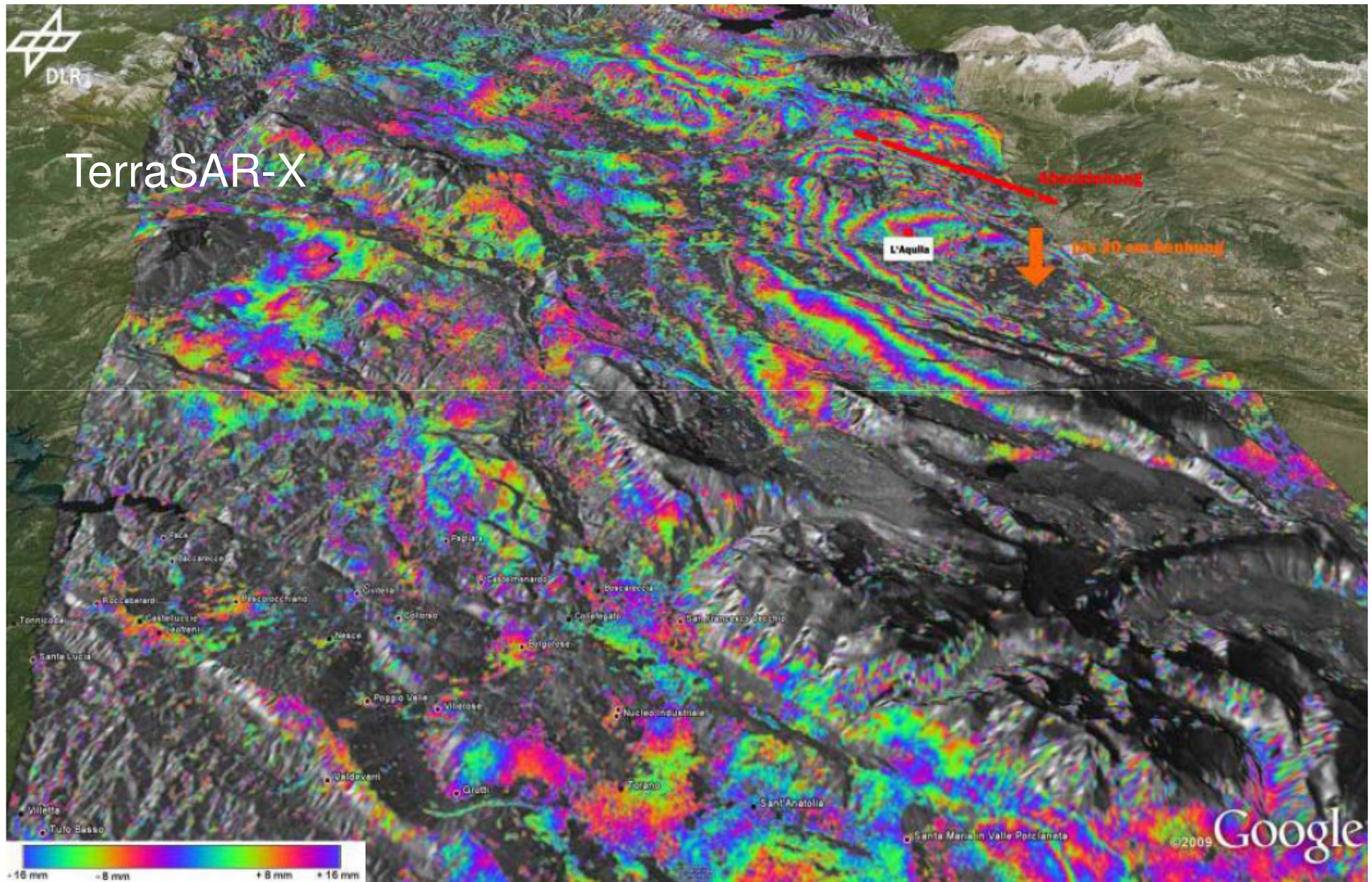
Etna

iso-altitude curves

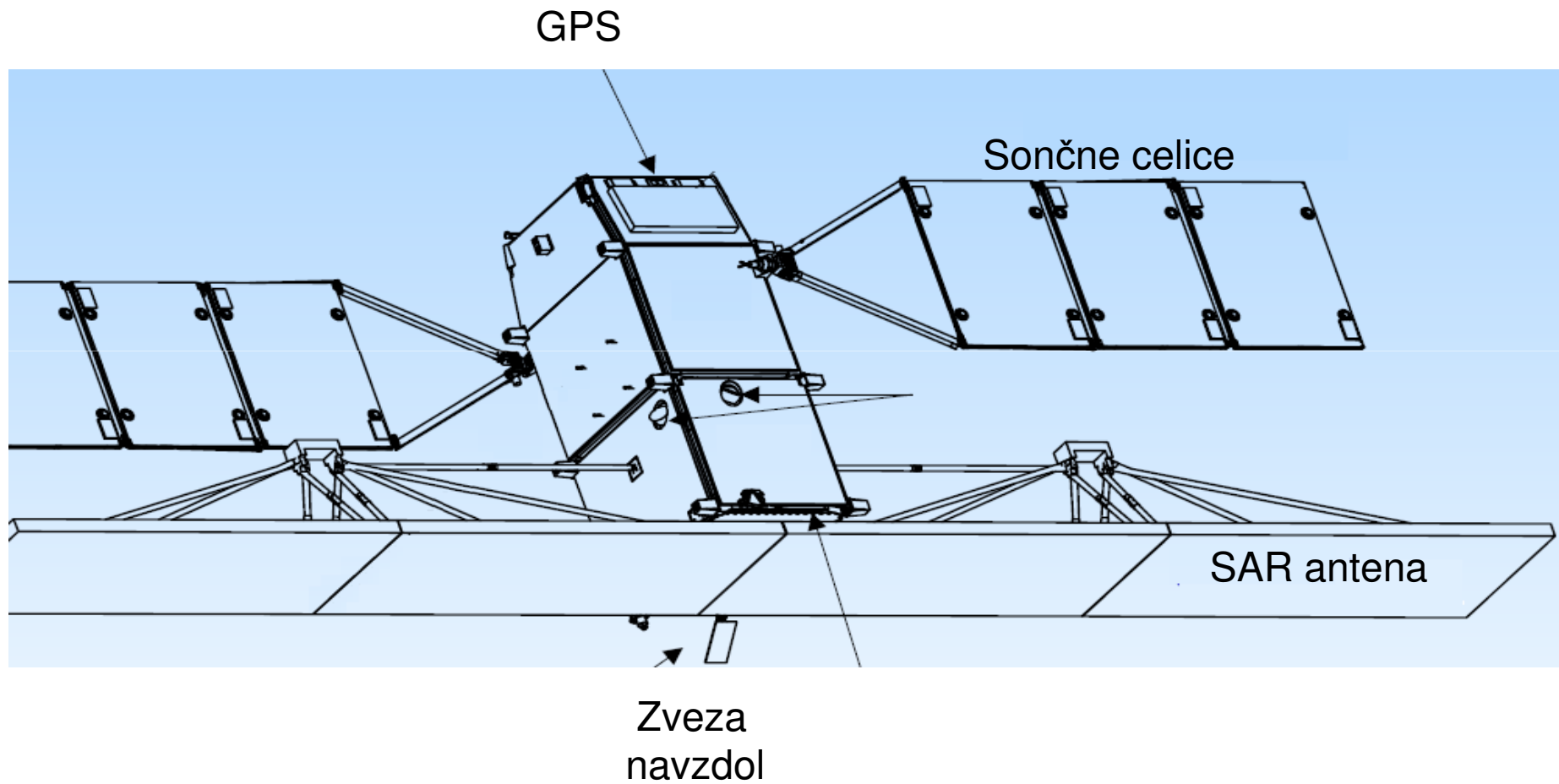
InSAR - digitalni model reliefa



L'Aquila, Italija, potres 2009

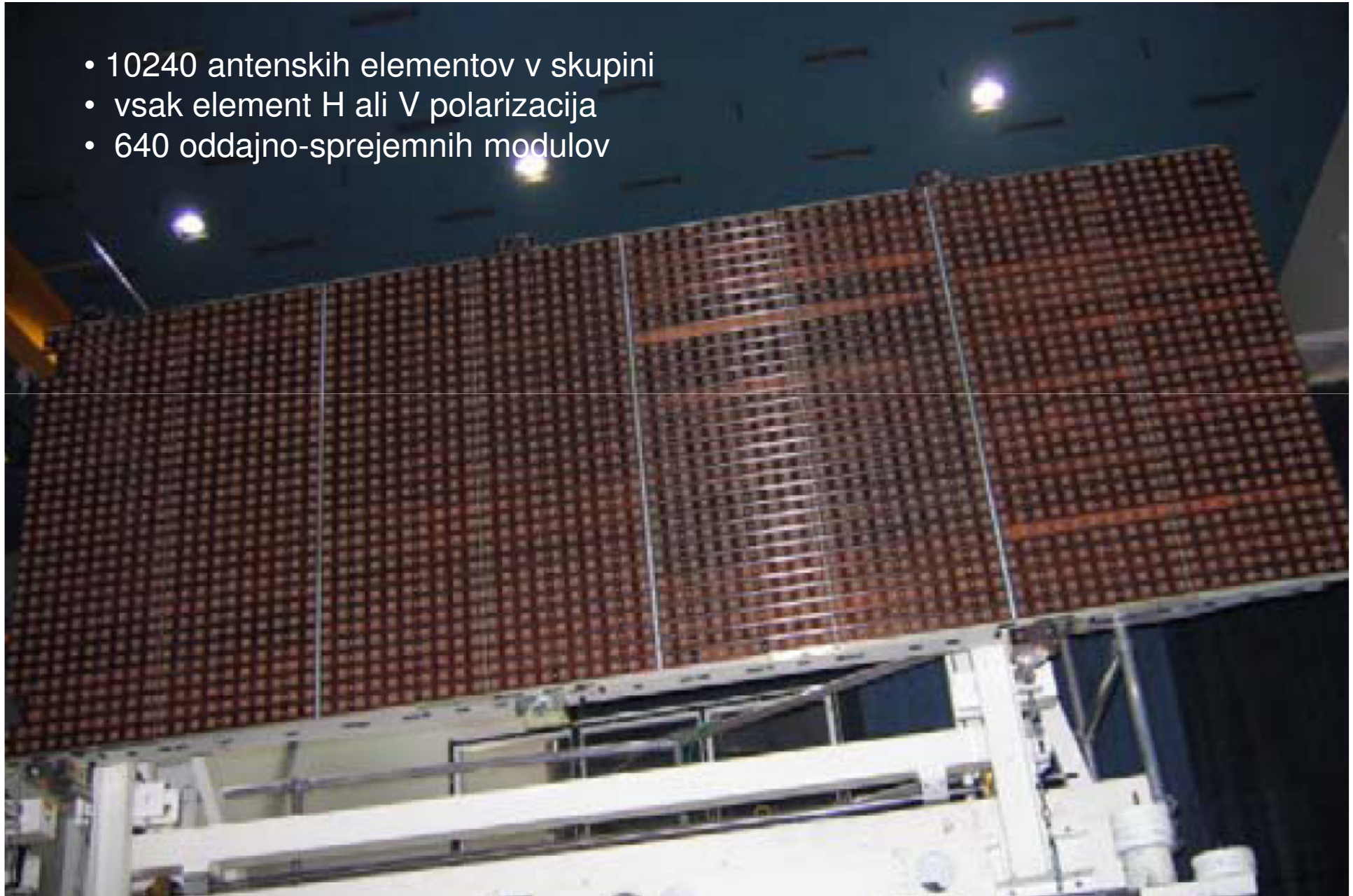


Antena RadarSAT -2



Antenska dvopolarizacijska skupina⁹¹

- 10240 antenskih elementov v skupini
- vsak element H ali V polarizacija
- 640 oddajno-sprejemnih modulov



CCR Trirobni retroreflektor
(odbija linearno polarizacijo)

Rabi kot referenčna točka

$$\theta_b = 37.0^\circ$$

$$\theta_{inc} = 17.7^\circ$$

$$\phi_s = 256^\circ$$

$$\phi_d = 13.9^\circ$$

$$\ell = 3.40 \text{ m}$$

$$\sigma = 34.2 \text{ dBm}^2$$

$$\theta_{lat} = 45^\circ 18' 15.5''$$

$$\phi_{long} = -75^\circ 46' 8.9''$$

$$H_{ellip} = 61.94 \text{ m}$$

2006.05.10 16:46



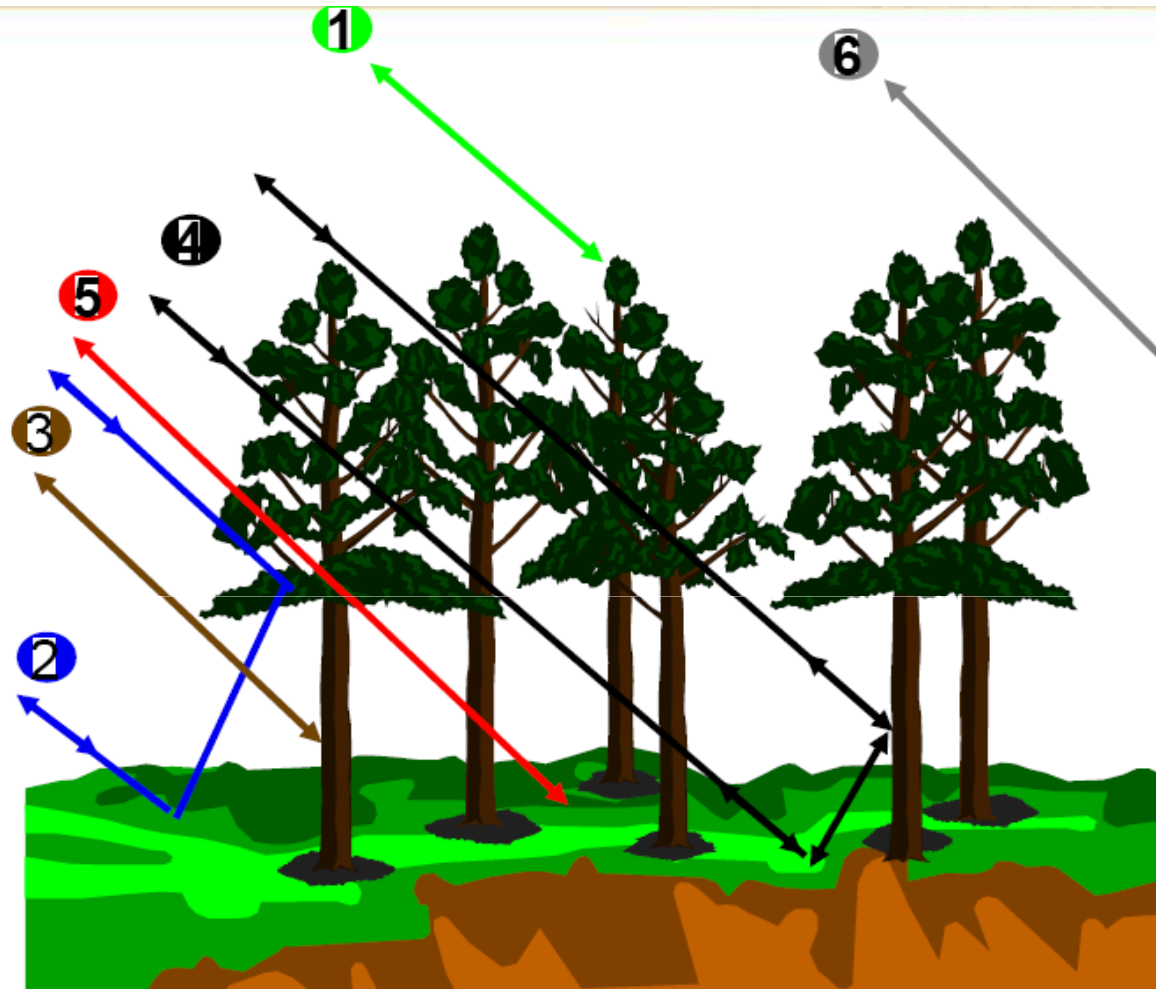
HyMAP image of Gilching, Germany
(R - 14, G - 9, B - 5)



| | |
|---|---|
|  Tile - Clay (1) |  Shingles - fiberglass (1) |
|  Tile - Clay (2) |  Shingles - fiberglass (2) |
|  Tile - Concrete |  Conglomerate/asphalt |
|  Road asphalt | |

Difuzni odboj na drevju

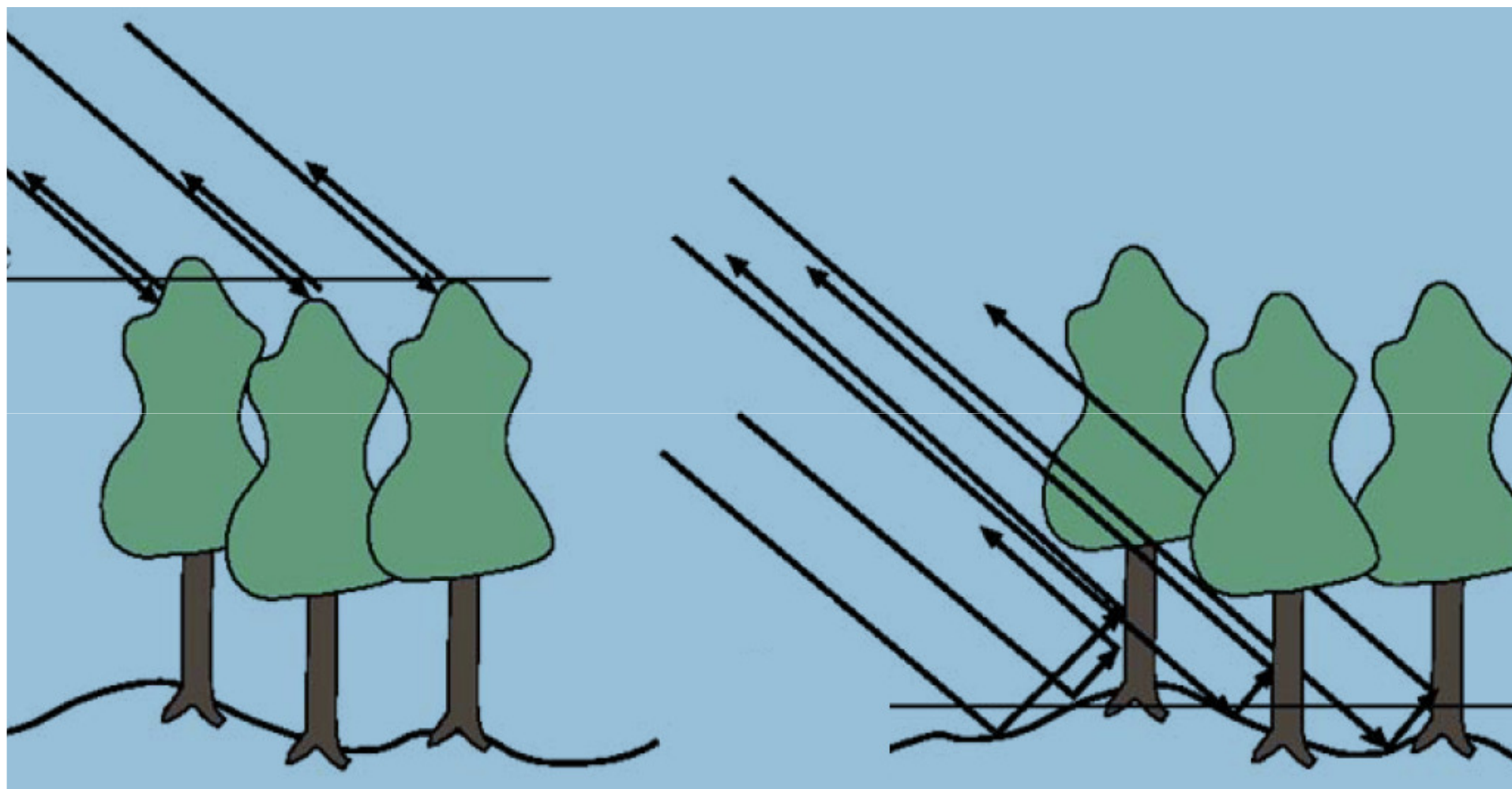
94



- 1 Odboj od krošnje
- 2 Odboj od vej
- 3 Odboj od debla

- 4 Odboj zemlja deblo
- 5 Odboj od zemlje

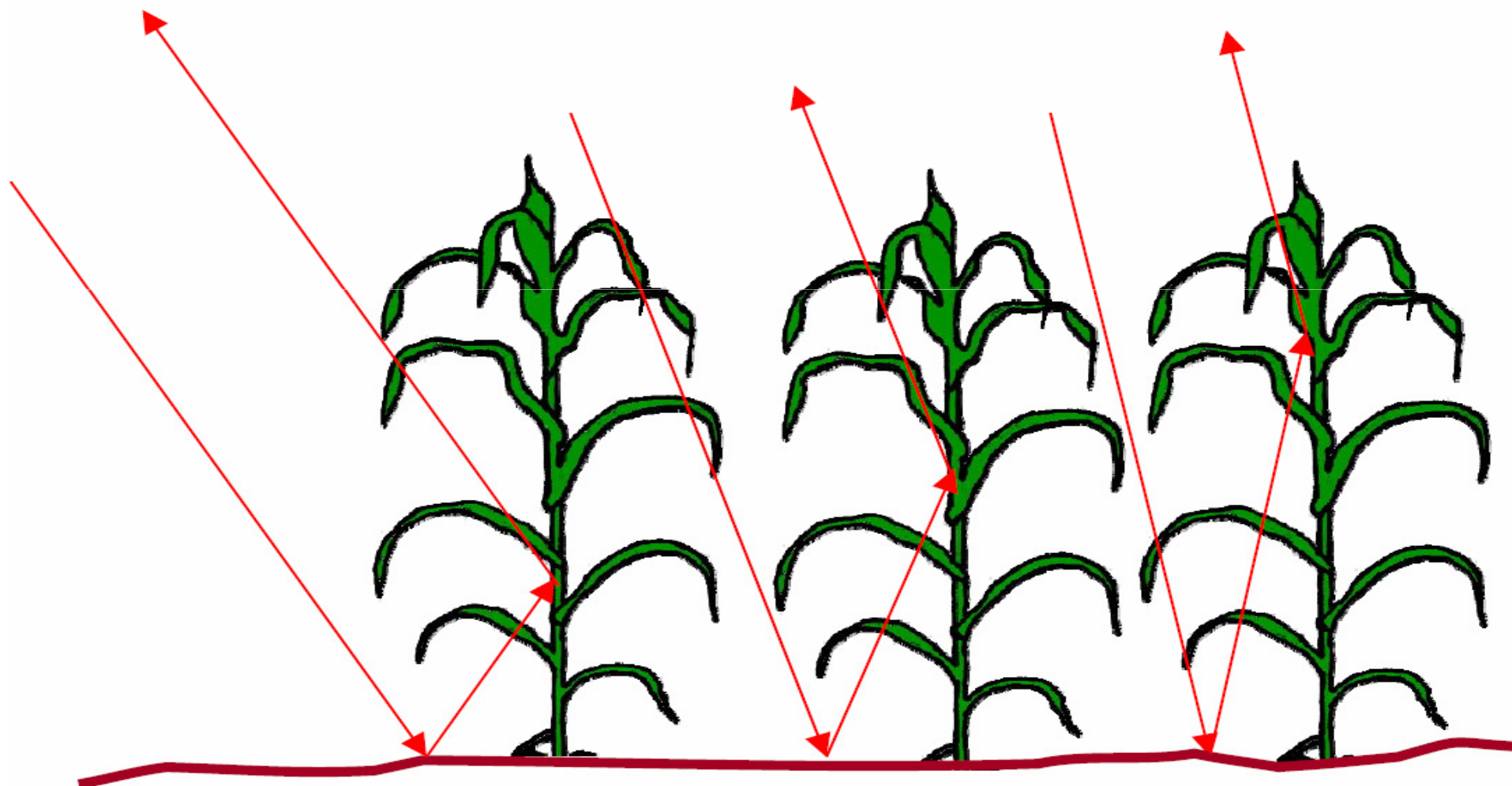
Vpliv frekvence na odziv gozda



Pas X

Pas P

Razprševanje na poljščinah



Razpršilci na drevesu



Igličasto drevo



Pas X (3 cm)



Pas L (30 cm)

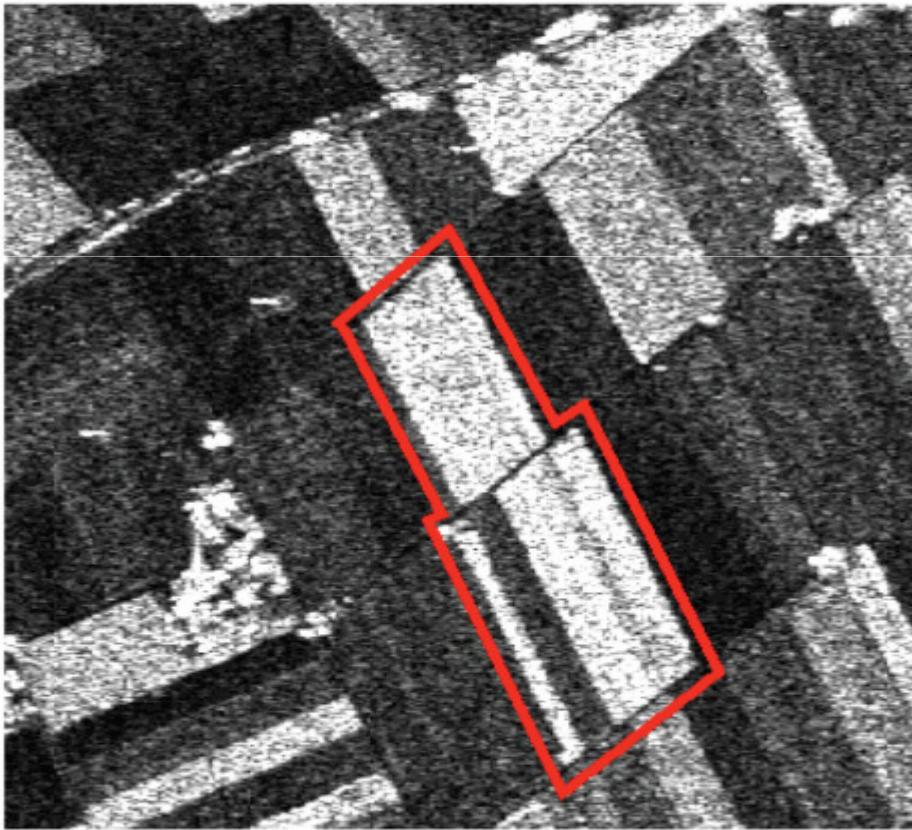


Pas P (70 cm)

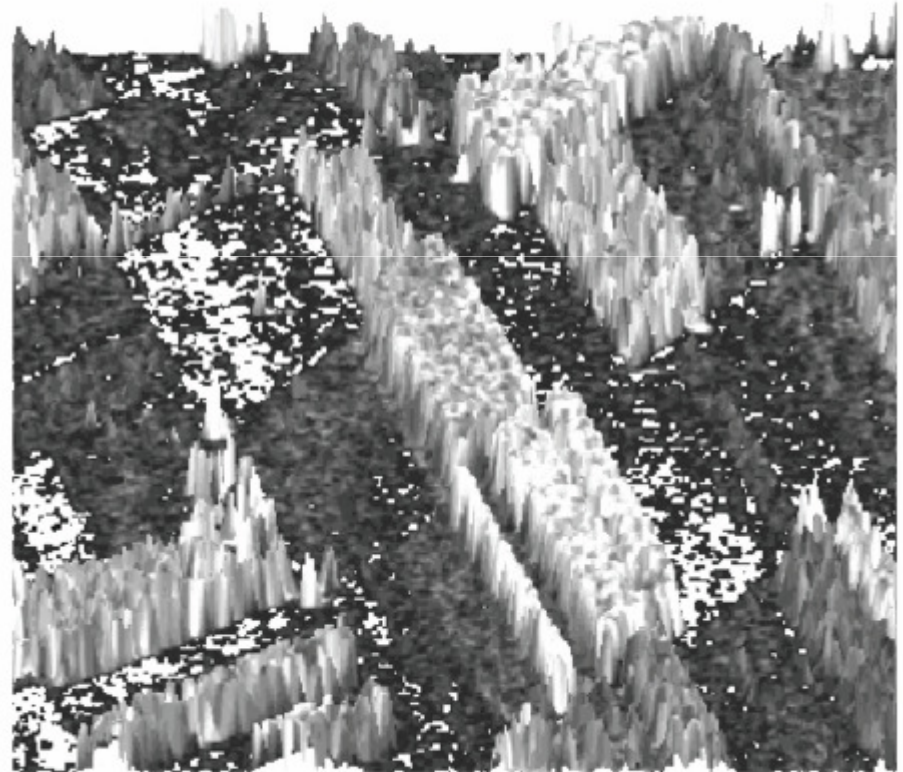


VHF (3 m)

ESAR / Test Site: Kuettighoffen , Switzerland



SAR Image L - band



Corn Height Map

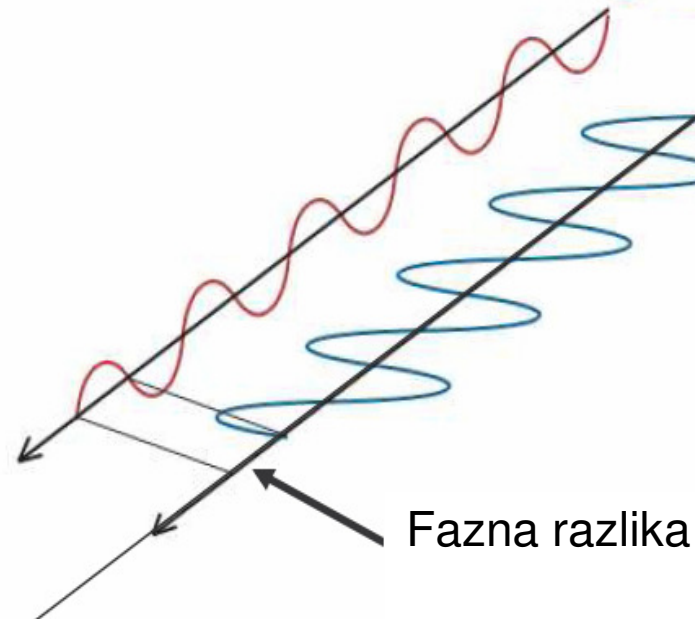
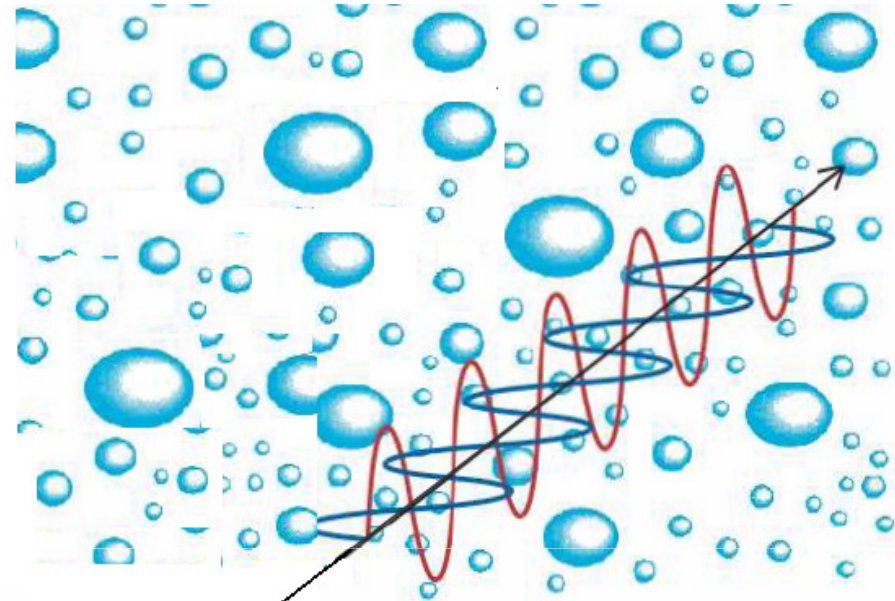
Polarimetrične predstavitve

1. Jonesova matrika
2. Mullerjeva matrika
3. Koherenčna matrika
4. Kovariantna matrika

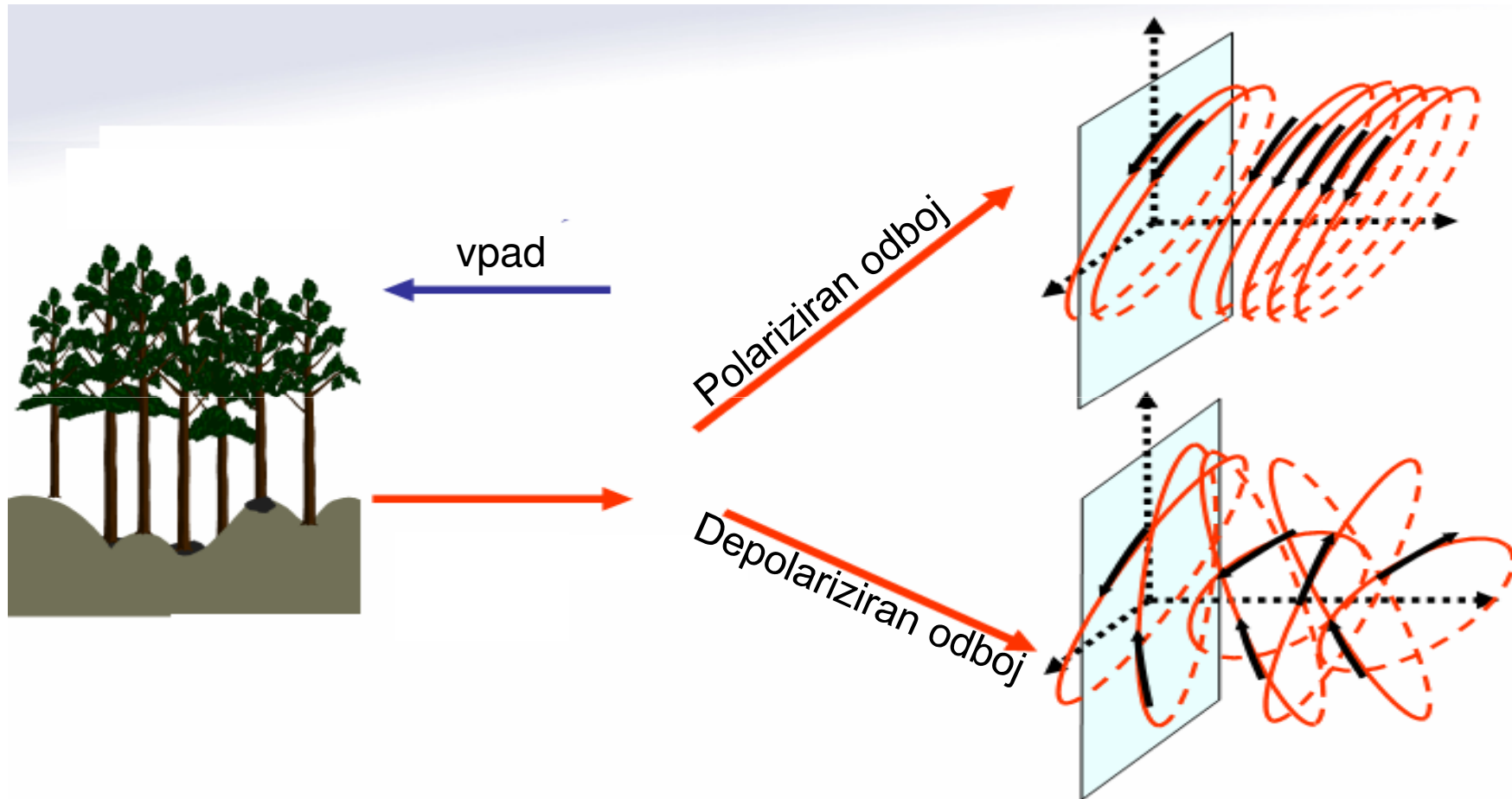
Polarizacija v meteorologiji

Zaradi sploščenosti dežnih kapljic se H polarizirani valovi močnejše odbijajo kot V polarizirani ($e_H > e_V$).

To privede do fazne razlike med H in V polariziranima valovoma, ki je merilo za neizotropnost snovi.



Depolarizacija pri odboju



Sklep

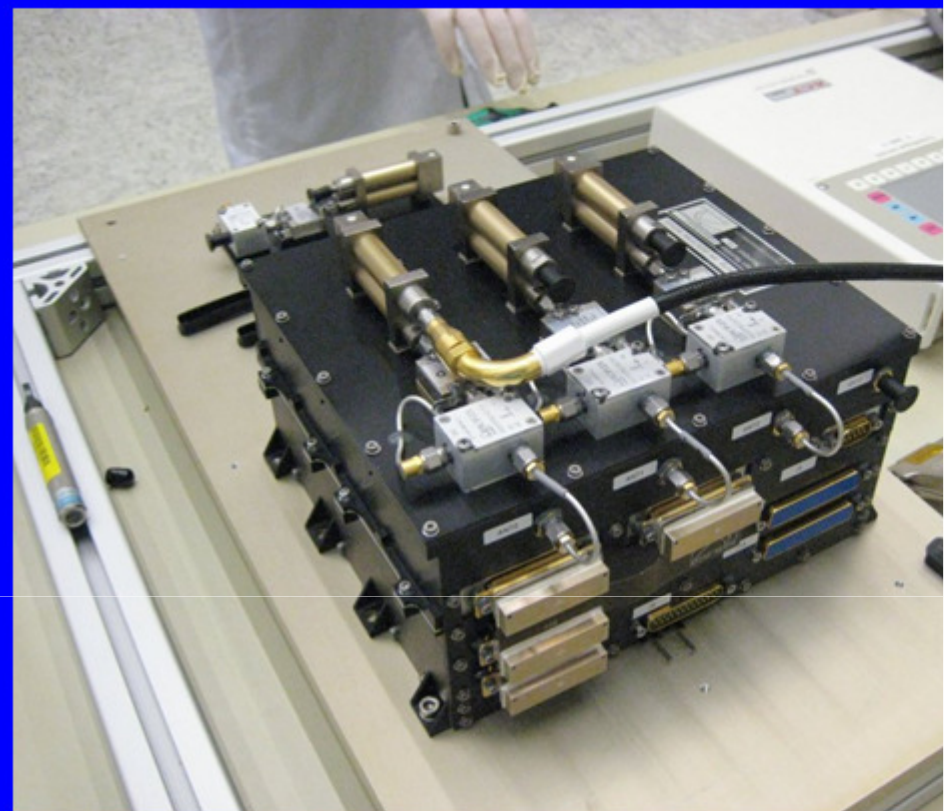
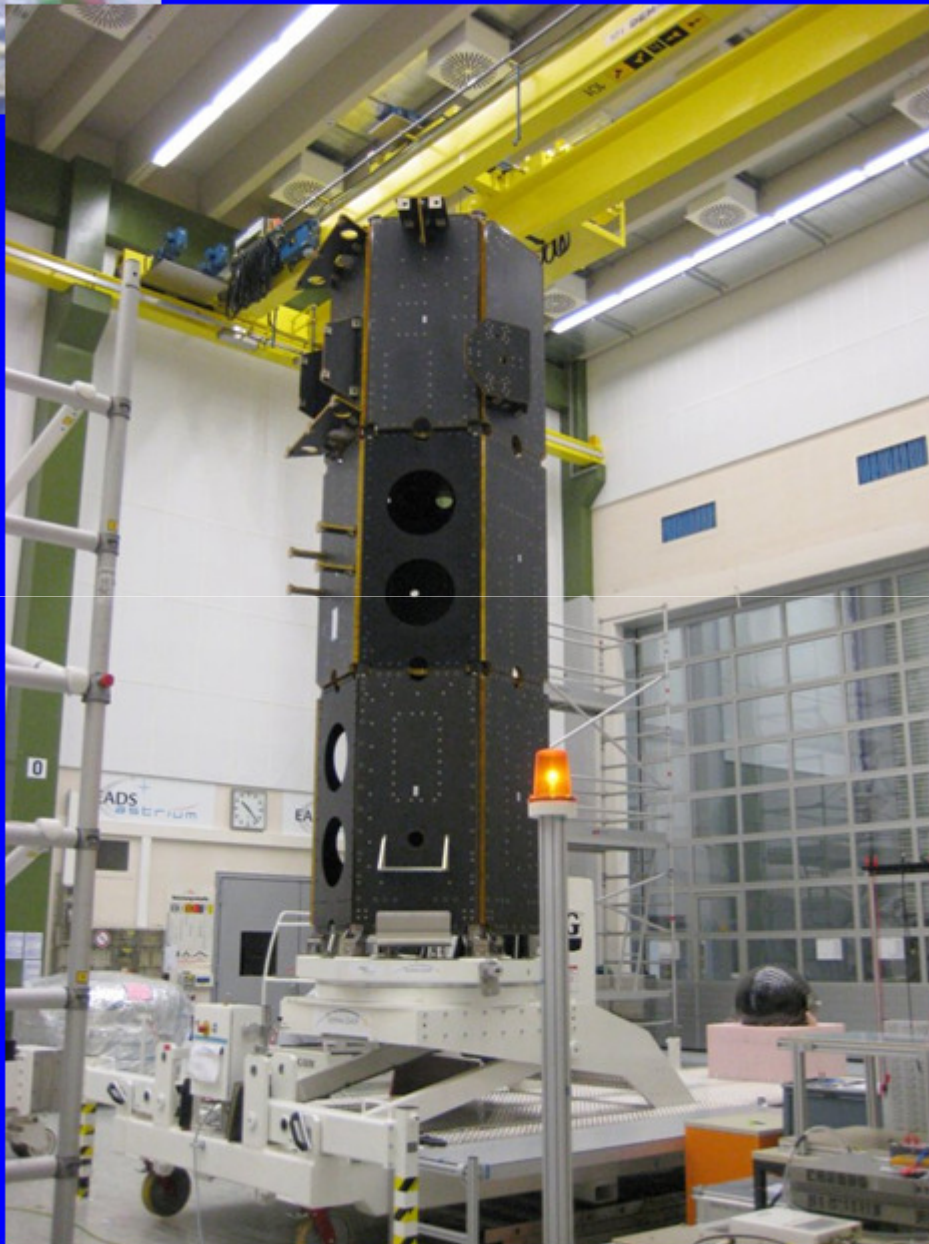
- Polarimetrija je aktivna radarska tehnika, ki omogoča zbiranje podatkov o bio-fizikalnih lastnostih zemeljskega površja.
- Pol SAR in Pol-InSAR so sodobne naprave, ki izkoriščajo polarizacijo kot dodatno informacijo (poleg amplitude in faze).
- Poznavanje osnov polarimetrije nam omogoča boljše razumevanje pomena polarizacije.
- Pomen polarizacije v radiokomunikacijah je zlasti v tehniki polarizacijske raznolikosti.

Konec

Oznake frekvenčnih pasov

| | | |
|---------------------|---------|----------|
| 500-1000 MHz | VHF (P) | C |
| 1-2 GHz | L | D |
| 2-3 GHz | S | E |
| 3-4 GHz | S | F |
| 4-6 GHz | C | G |
| 6-8 GHz | C | H |
| 8-10 GHz | X | I |
| 10-12.4 GHz | X | J |
| 12.4-18 GHz | Ku | J |
| 18-20 GHz | K | J |
| 20-26.5 GHz | K | K |
| 26.5-40 GHz | Ka | K |

TanDEM-X

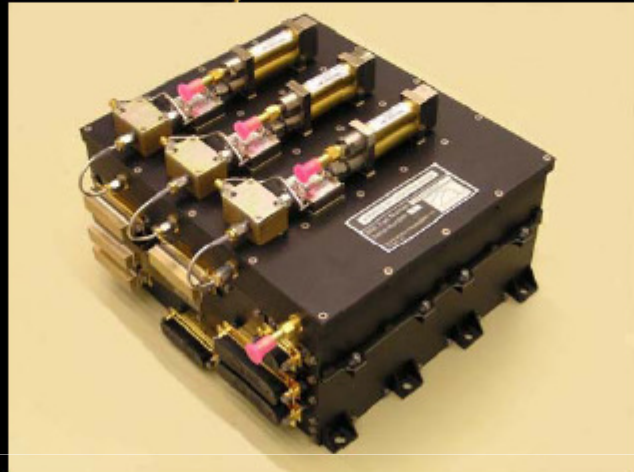


Dual-frequency GPS receiver IGOR™

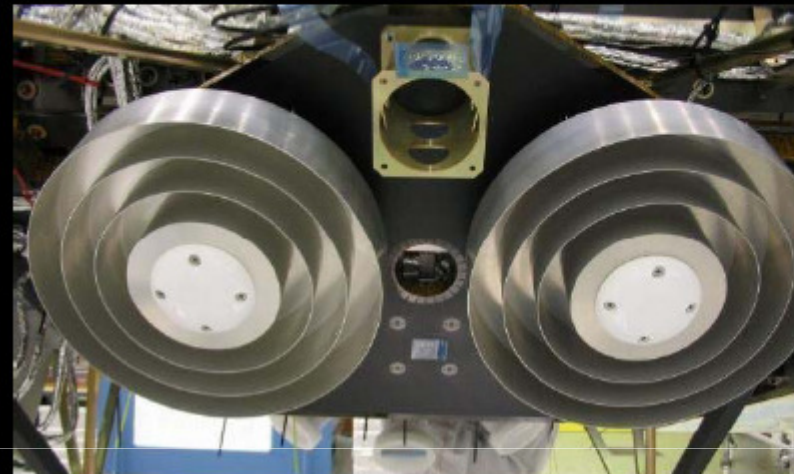
Derived from JPL's BlackJack GPS receiver for Jason-1/-2, CHAMP, GRACE, SAC-C

Design especially „hardened“ against inter X-Band radar frequencies

GPS and SLR Hardware



GPS receiver (IGOR)



POD antennas (zenith)



GPS RO antennas

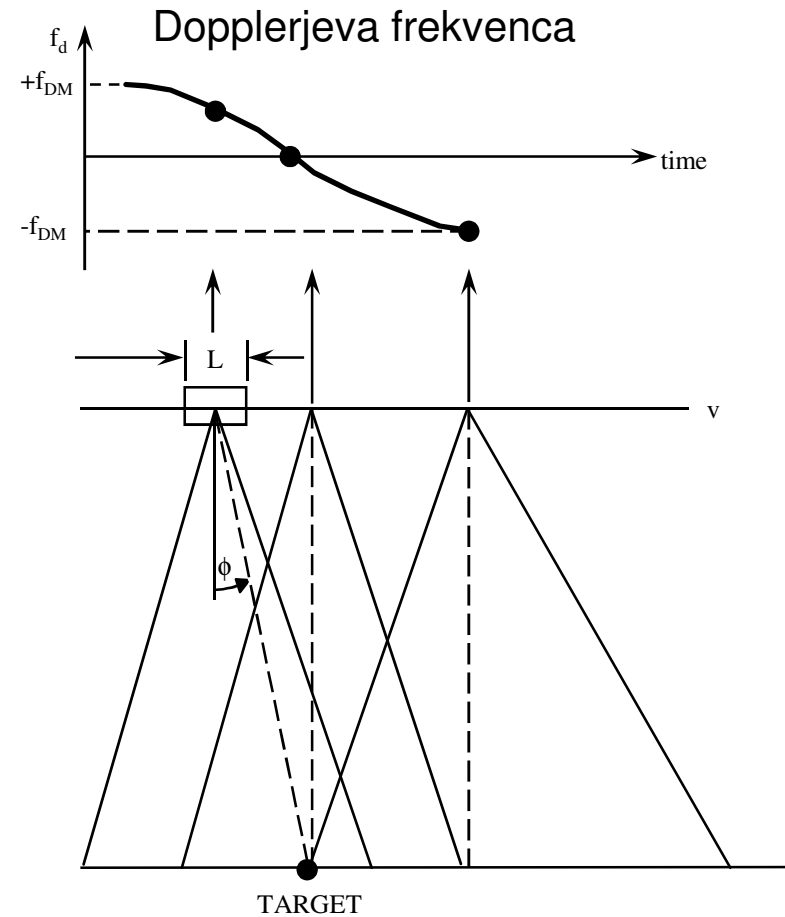
Princip SAR

$$f_d = \frac{2v}{\lambda} \sin \phi$$

$$X_r = \frac{c}{2BW \sin \theta}$$

$$X_a = \frac{v}{2f_{DM}} = \frac{L}{2}$$

$$S = \frac{h\lambda}{W \cos^2 \theta}$$



Resolucija po razdalji in resolucija po azimutu sta neodvisni od razdalje

Osnove radarja bočnega obzora

Resolucija po razdalji:

$$X_r = \frac{c \tau}{2 \sin \theta} = \frac{c}{2 BW \sin \theta}$$

Resolucija po azimutu:

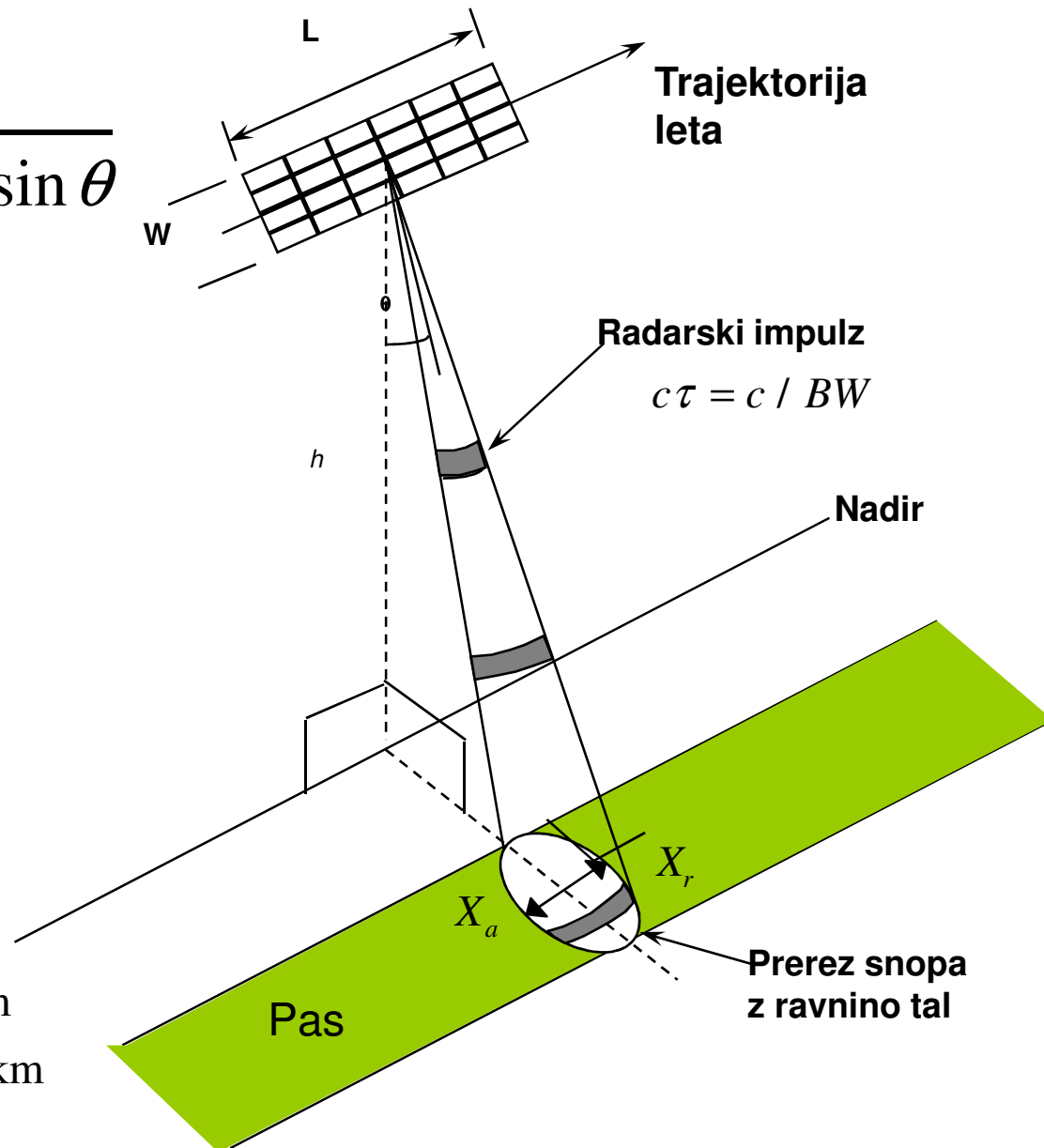
$$X_a = \frac{h \lambda}{L \cos \theta}$$

Širina pasu:

$$S = \frac{h \lambda}{W \cos^2 \theta}$$

Primer:

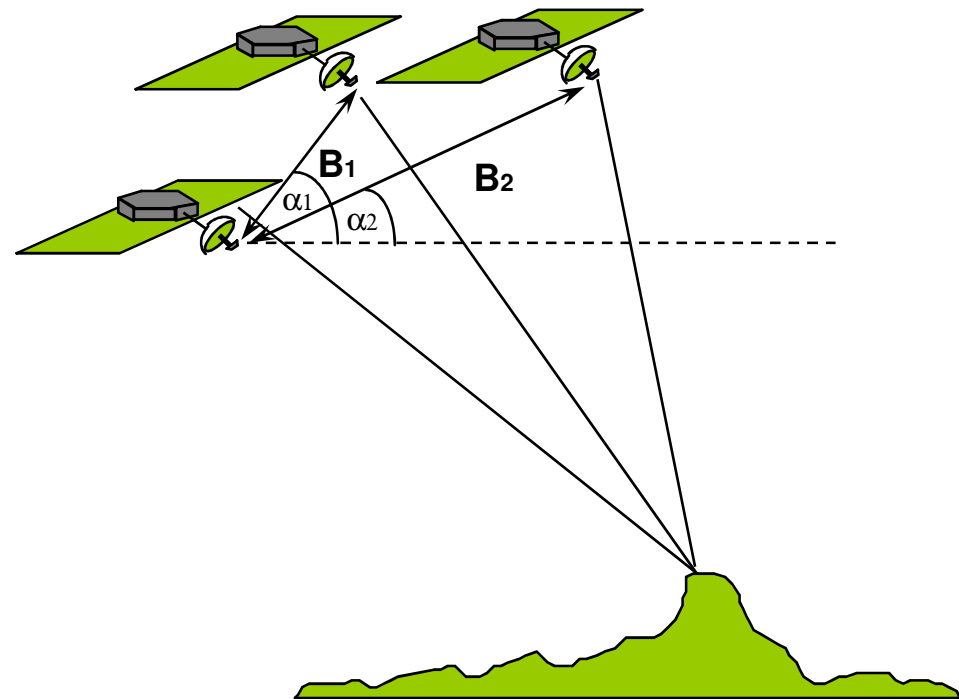
$$\left. \begin{array}{l} h = 800 \text{ km} \\ \lambda = 24 \text{ cm} \\ BW = 20 \text{ MHz} \\ \theta = 35^\circ \end{array} \right\} \Rightarrow \begin{array}{l} X_r = 13 \text{ m} \\ X_a = 20.5 \text{ km} \end{array}$$



Diferenčna interferometrija

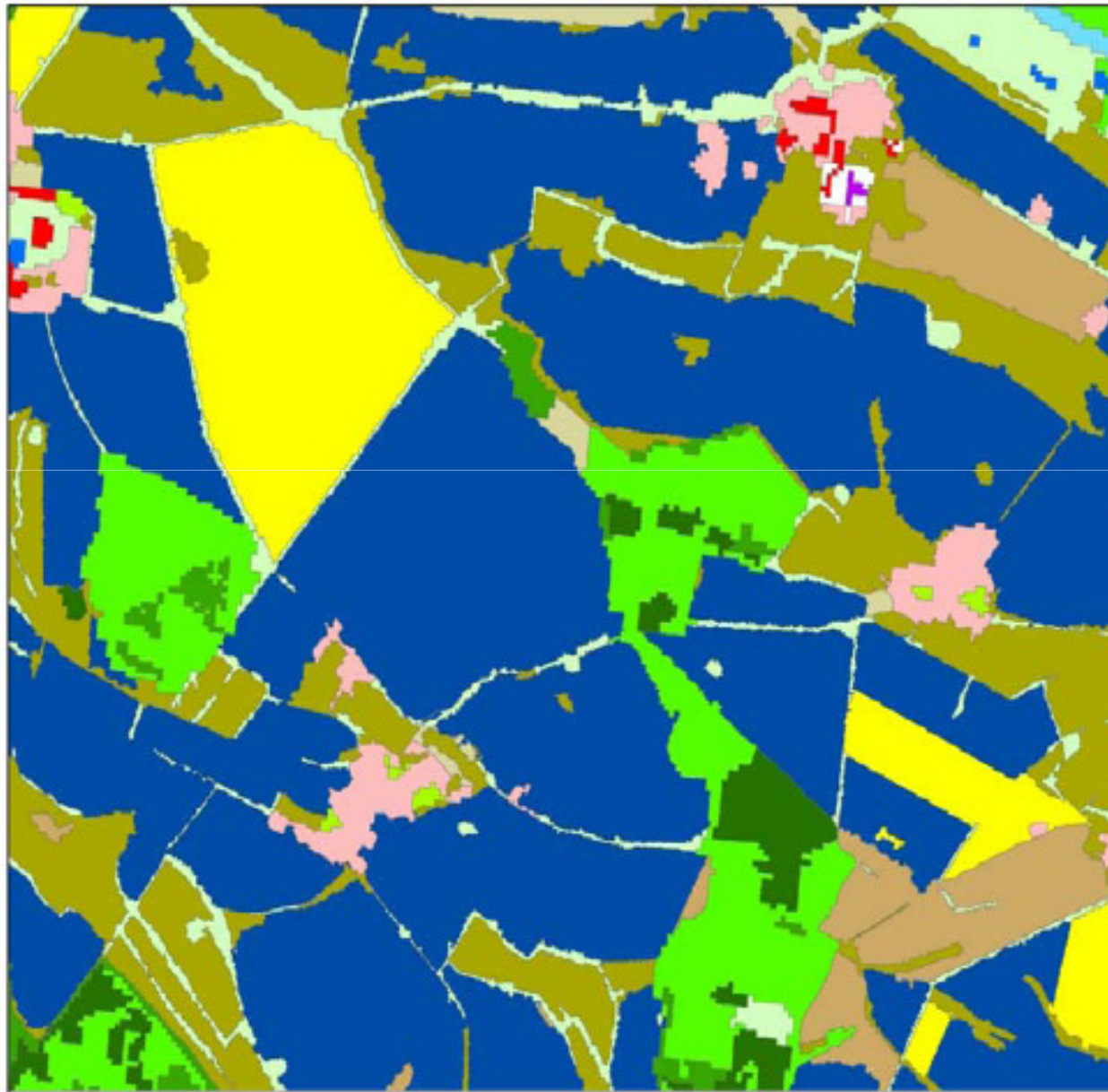
$(B_1, \alpha_1); (B_2, \alpha_2)$

$$\Delta\phi_2 - \Delta\phi_1 \left(\frac{B_2 \sin(\alpha_2 - \theta)}{B_1 \sin(\alpha_1 - \theta)} \right) = 0$$



Trikratni prelet, dve različni bazi

| | |
|--------------------------------------|------------------------|
| Height | 5.0 m |
| Wet mass | 1.230 kg |
| incl. payload mass | 394 kg |
| SAR Antenna | 4.8 m x 0.7 m x 0.15 m |
| Resolution | 1 m @ 5 x 10 km Scene |
| Power consumption | 800 W average |
| Data storage | 256 Gbit |
| Data transmission | 300 Mbit/s |
| | X-Band Downlink |
| Orbit | 514 km |
| | 98° Inclination |
| | sun-synchronous |
| Repetition rate (orbit repeat cycle) | 11 days |
| Life time | 5 years |



















 The classification result
ground truth informatio

 The results have been e
the art (optical data). Th
with optical data is abo

 Cross check of radar, a

Agri-Environmental Classes

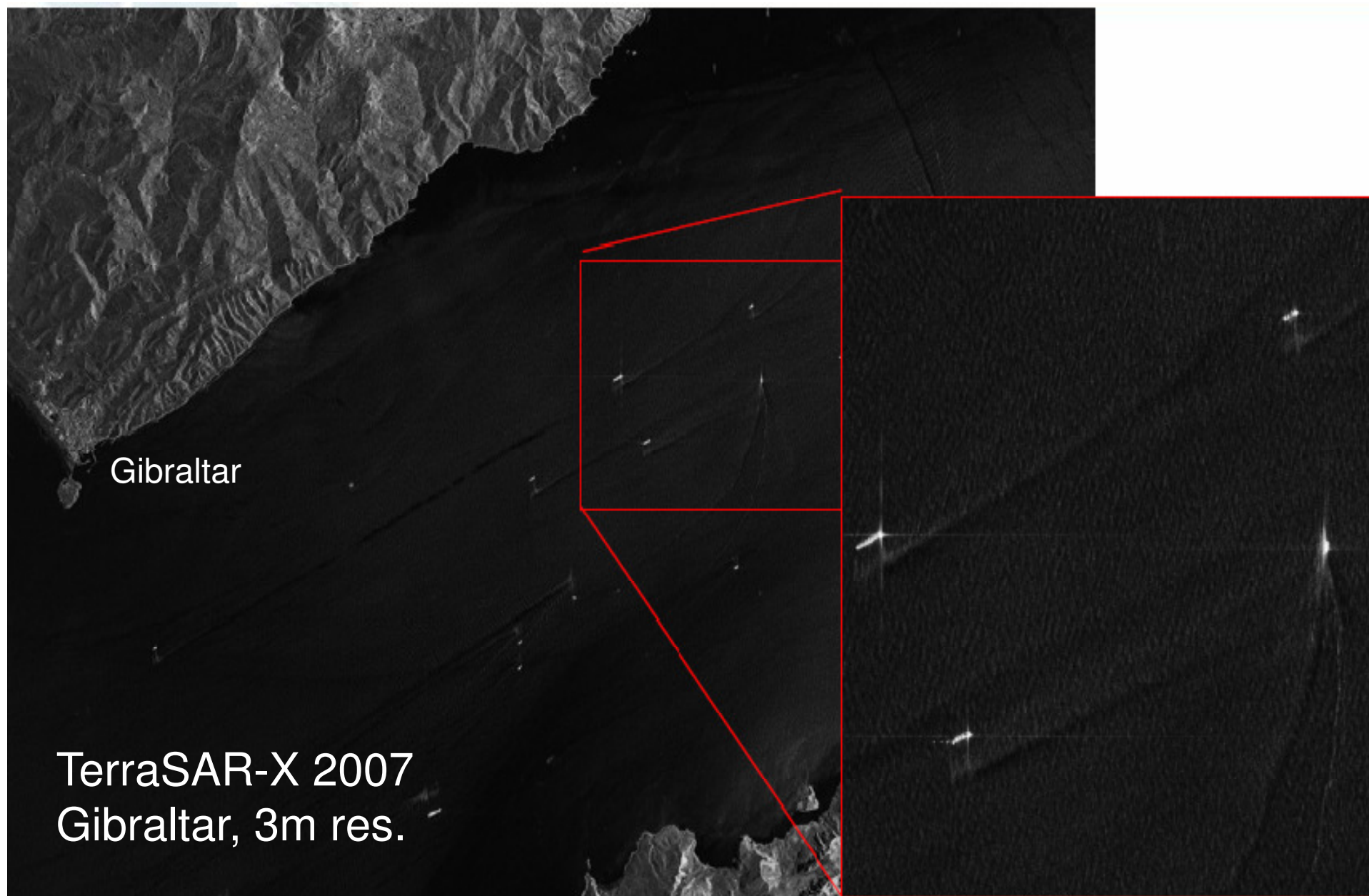
-  Village and Suburban
-  Urban Sealed areas
-  Dense Urban
-  Urban Fabric
-  Urban Green
-  Coniferous forest
-  Deciduous forest
-  Mixed forest
-  Species Woodland
-  Natural other open areas
-  Cereals
-  Rape
-  Grassland & Set-aside
-  Root Crops & others
-  Stream courses
-  Water bodies

- The radar classification performed better in the detecting cereals compared to optical remote sensing. This is due to the fact that the spectral reflectance of cereals (wheat, rye, barley) is very similar at these phenological stage.
- Radar, which is more sensitive to structural differences in plant morphology is able to differentiate the crops by there plant size. It was also possible to detect sugar beet and peas by radar at that early development stage.
- Optical data performed slightly better at oilseed rape detection because at the beginning of flowering the spectral reflectance is very dominant compared to other crops.
- Fields classified as “set a side” are a specific problem, they can be grassland, sunflowers or oilseed rape

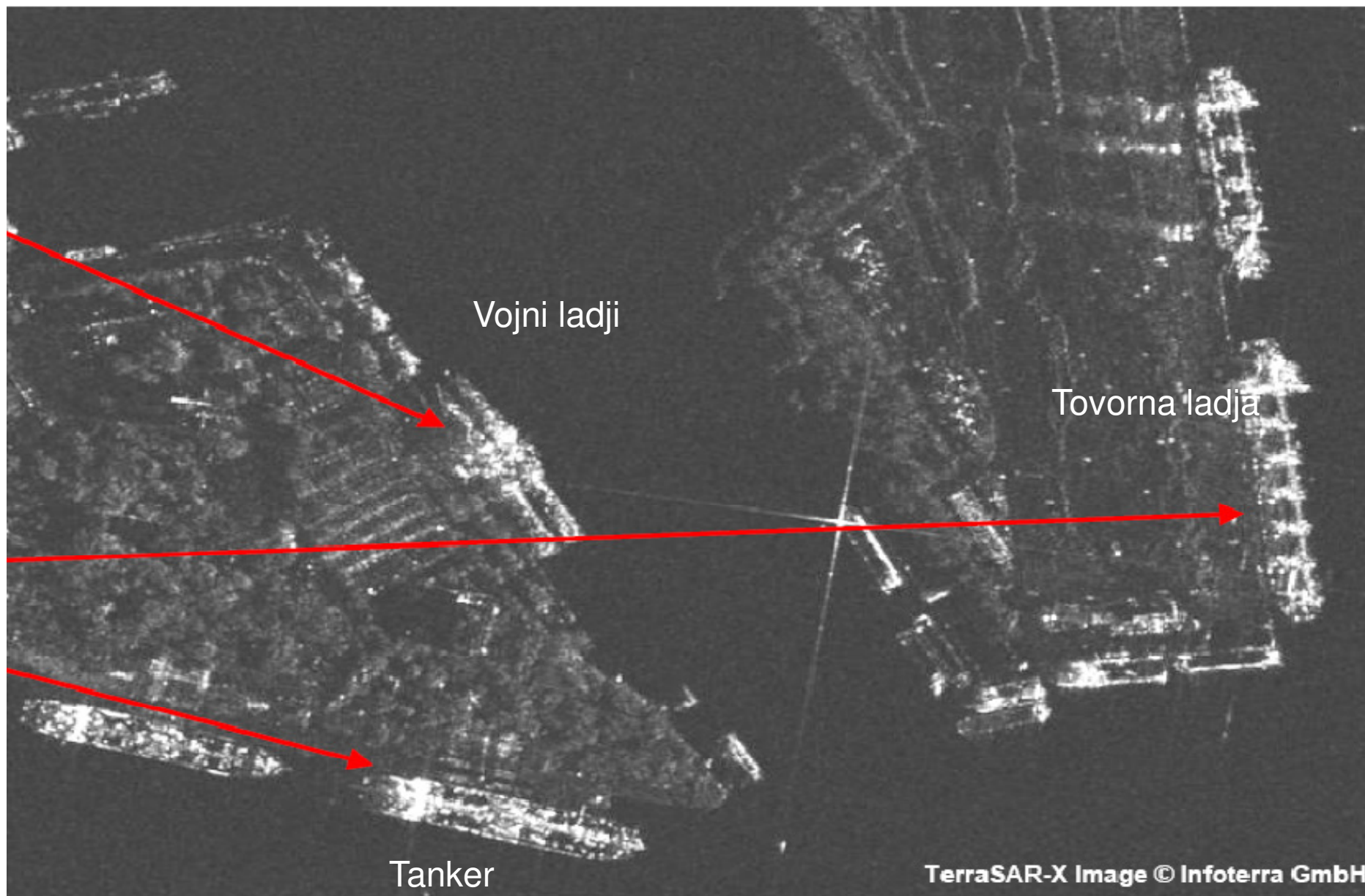
Berlin

TerraSAR-X

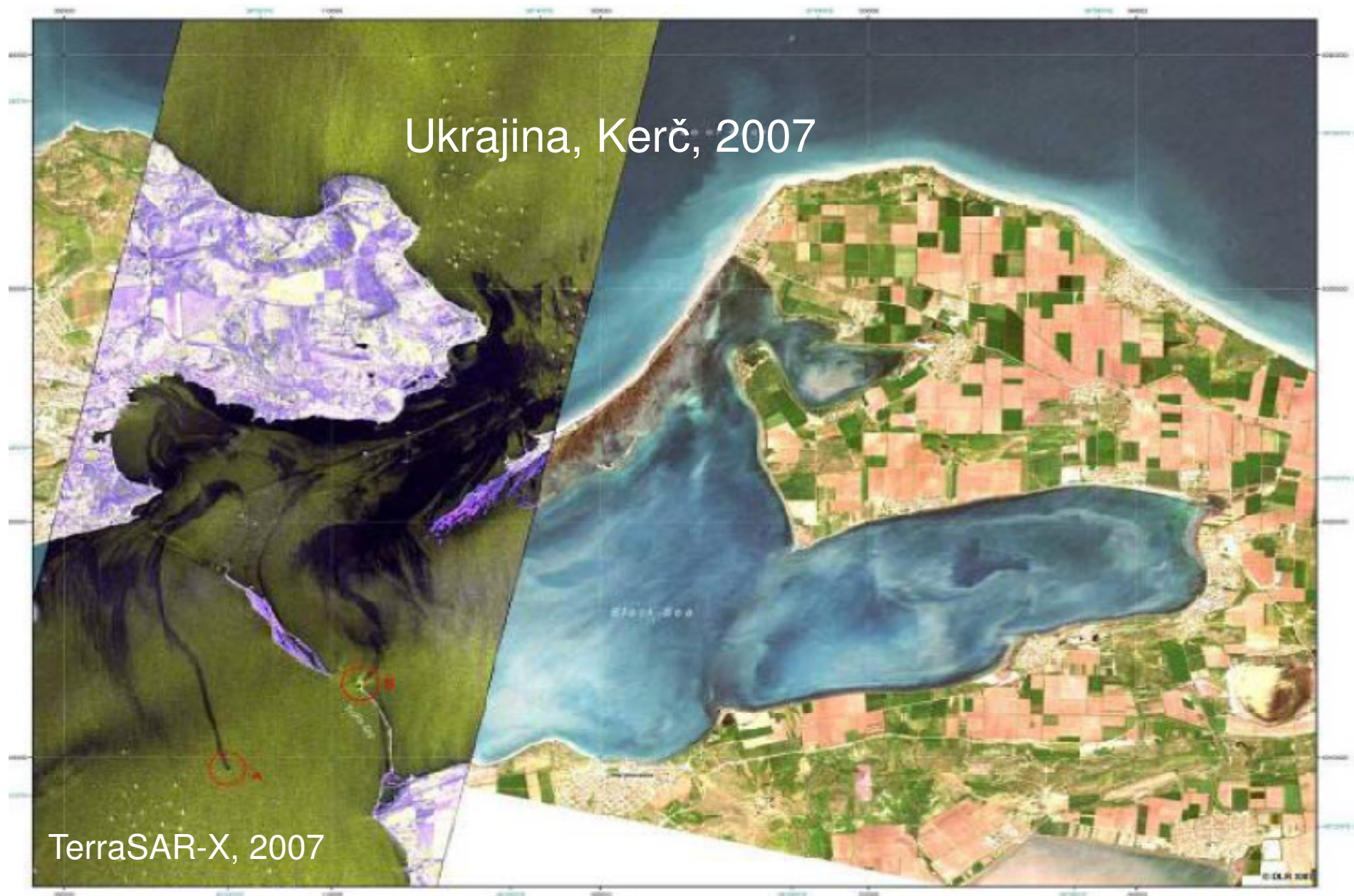


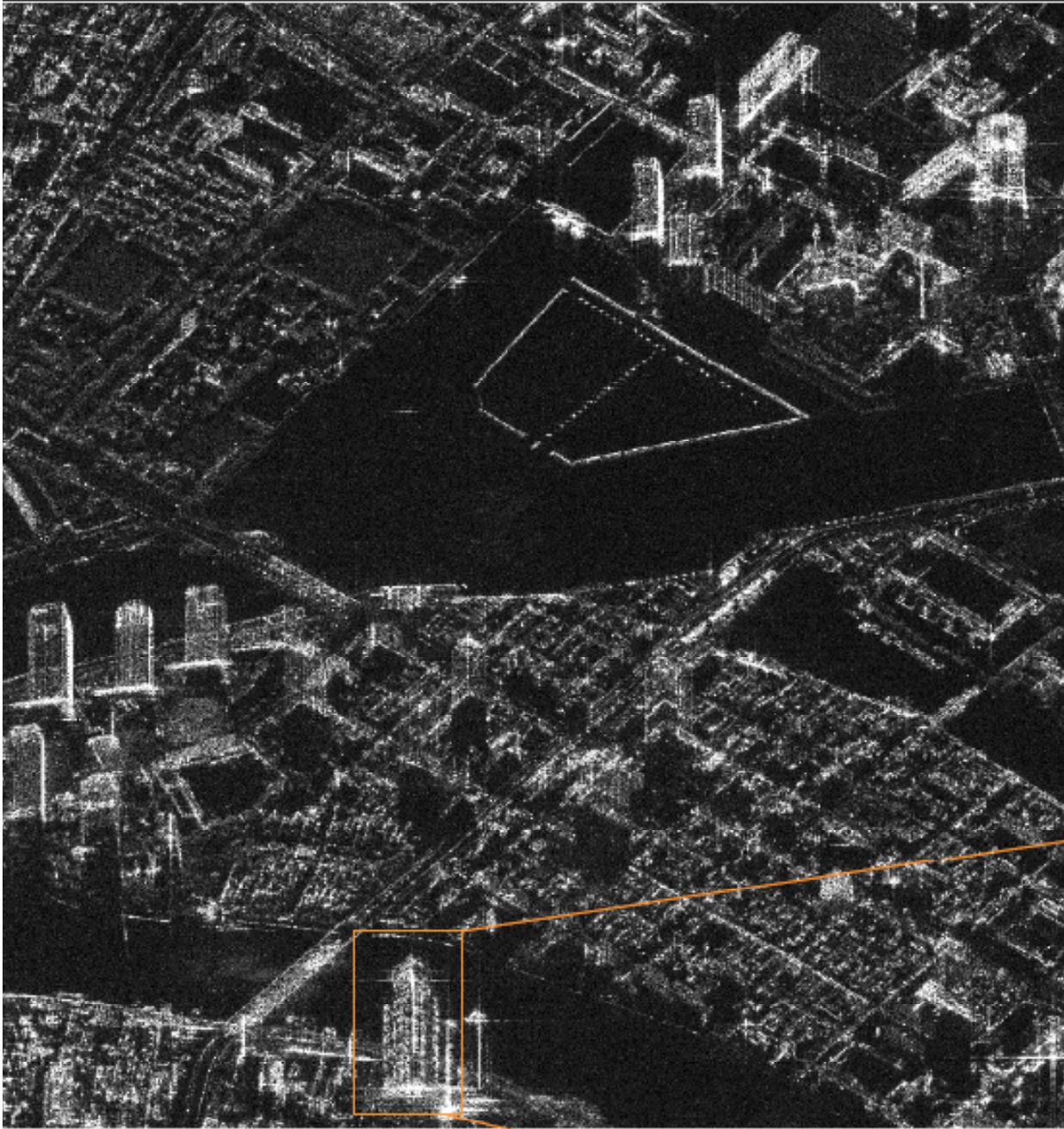


Nadzor ladijskega prometa

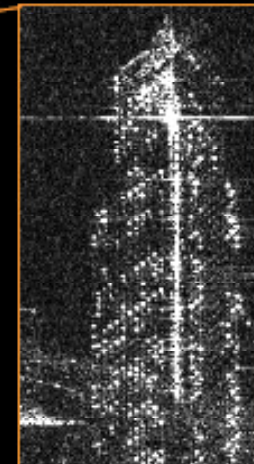


Odkrivanje naftnih madežev





Google

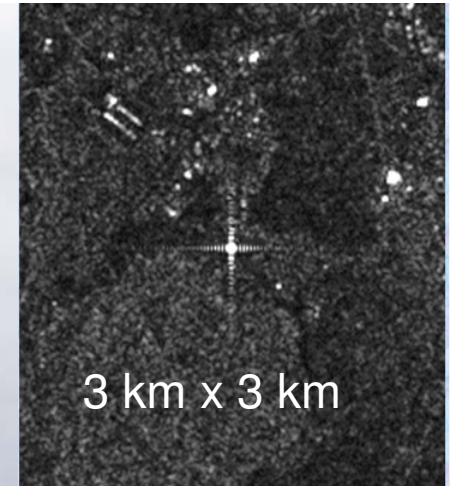
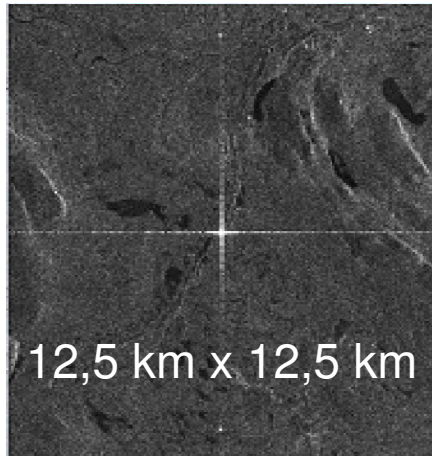


AR-X scene, Tokyo River Island

Myanmar, ciklon, poplave, 2008



Odbojni odziv triroba

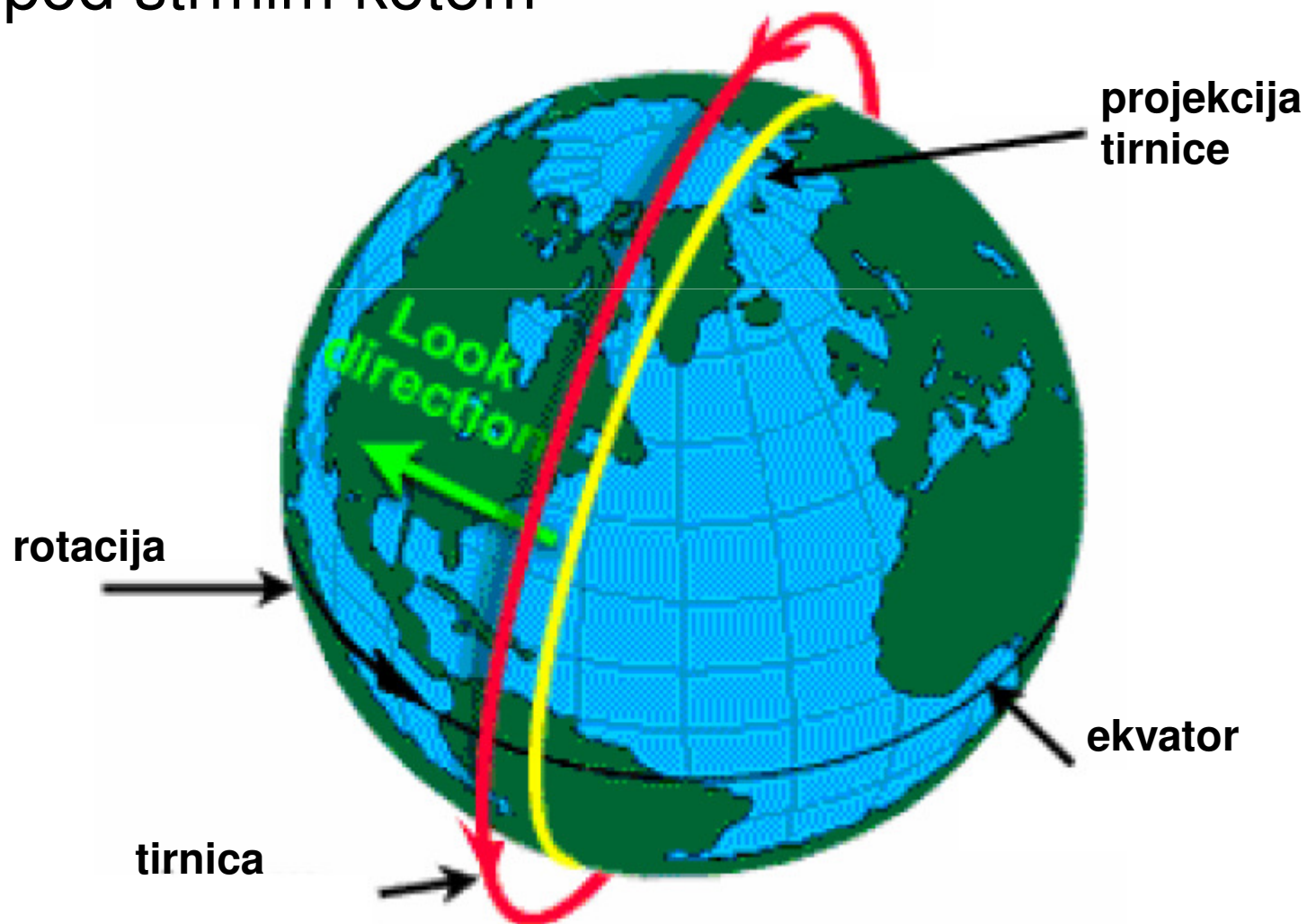


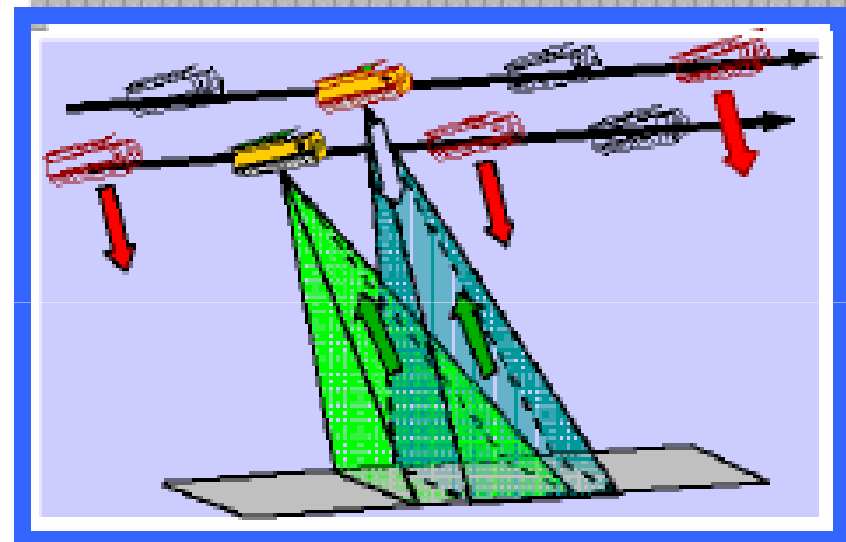
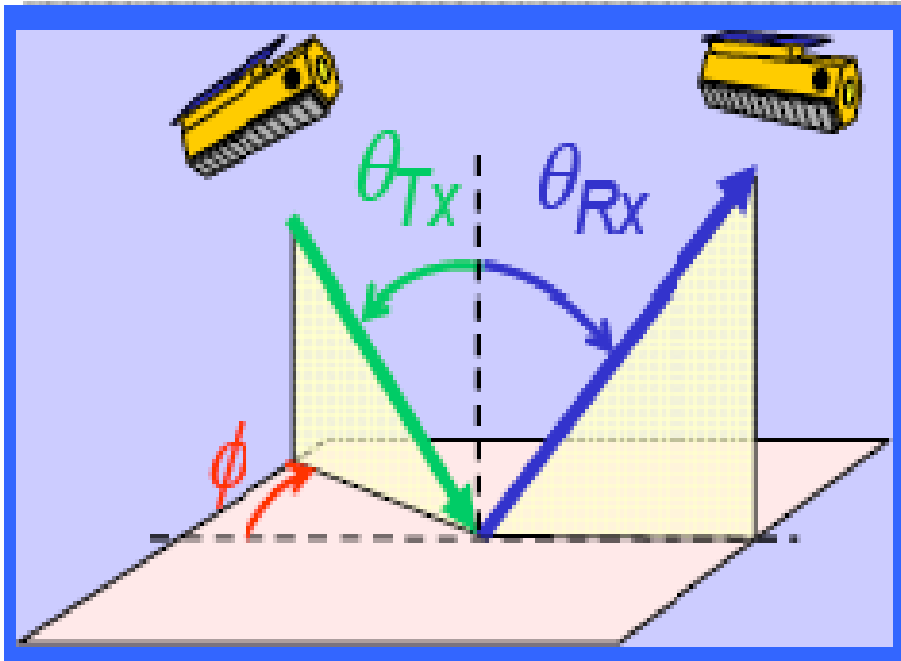
| Instrument | Operational dates | Orbit alt. (km) Inclin. angle (°) | Revisit time | Swath width (km) | Spatial resolution (m) | System specs | Inclination |
|------------------------------|---------------------------------------|--------------------------------------|--------------|-----------------------|-------------------------------------|--|----------------------|
| OS PALSAR (XA) | Jan 2006- | 691 km 98.16° | 46 days | 70 70 30 350 | 10 20 30 70 | L-band (observation strategy modes) HH HH + HV HH + HV + VH + VV ScanSAR HH | 34.3 34.3 21.5 |
| VISAT ASAR (A) | 2002- | 800 km 98° | 35 days | 100 400 | 30 150 1000 100 km | C-band Image mode VV or HH Dual pol mode VV+HH or VV+VH or HH+HV Wide swath mode VV or HH Global monitoring mode HH or VV Wave mode VV or HH | 15-4 |
| Radarsat-1 (SA) | 1995- | 798 km 98.6° | 24 days | 35-500 | 10-100 | C-band HH only | S1 S7 |
| Radarsat-2 (SA) | Dec 2007- | 798 km 98.6° | 24 days | 20-50 25 50-500 | 3-11 11-25 10-100 | C-band selective single pol polarimetry selective pol | 16.5 20-4 30-4 |
| Terrestrial SAR-X (R) | June 2007- | 512 km 97.4° | 11 days | 10 30 100 | 1 3 18 | X-band Single/dual/quad pol Spotlight Stripmap Scansar | 20-4 |
| SMO-SkyMed (S) | CSM 1 June 2007 CSM 2 Dec 2007 | 619 km 97.0° | 16 days | 10 10-100 100 | 1* 3* 30 *single look | X-band Single/dual pol Spotlight Stripmap Scansar | 25-4 |

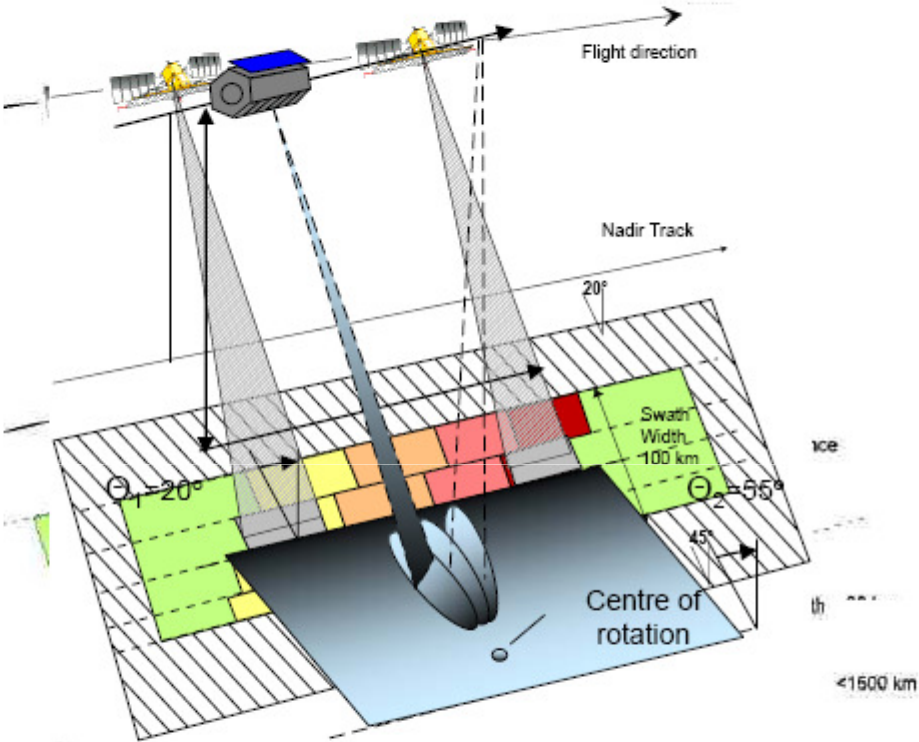


RadarSAT tirnica

Helio-sinhrona tirnica
pod strmim kotom







TerraSAR-X Imaging Modes

- Stripmap Mode*
- ScanSAR Mode*
- Spotlight Mode (Sliding)*
- HighRes Spotlight Mode (Sliding)*

| | Stripmap | ScanSAR | Spotlight | HighRes Spotlight |
|-----------------------------|--------------|---------------|-----------|-------------------|
| full perf. inc, angle range | 20° - 45° | 20° - 45° | 20° - 55° | 20° - 55° |
| scene size along track | acqu. length | acqu. length | 10 km | 5 km |
| scene size ground range | 30 km | 100 km | 10 km | 10 km |
| single look az. resolution | 3 m | 16 m | 2 m | 1 m |
| single look range | | 16 m (ground) | | |



Radar signal - surface interactions



Free (liquid) water
= smooth surface

→ dark

Urban area
= rough surface

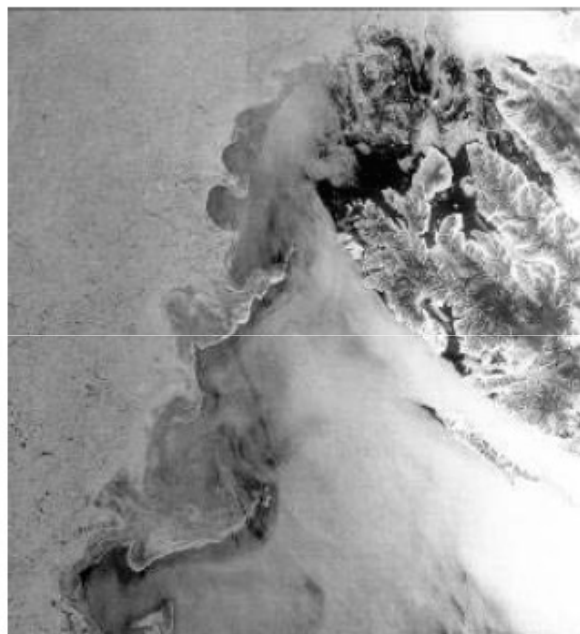
→ bright

Ploughed fields
= rough surface

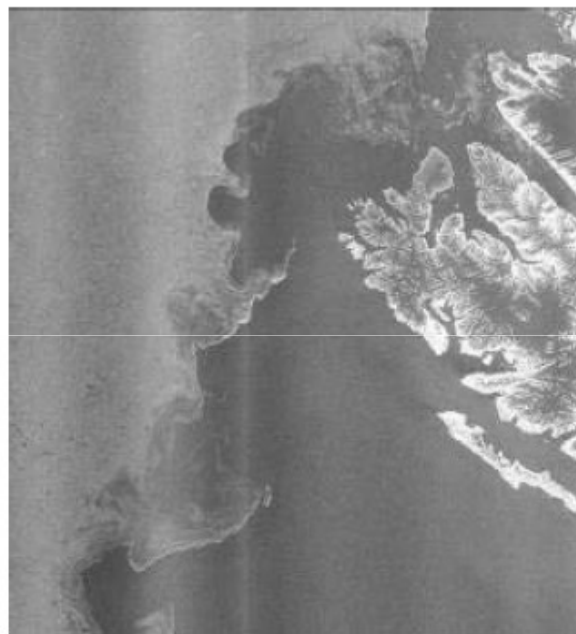
→ bright

Crop at early stage
= smooth surface

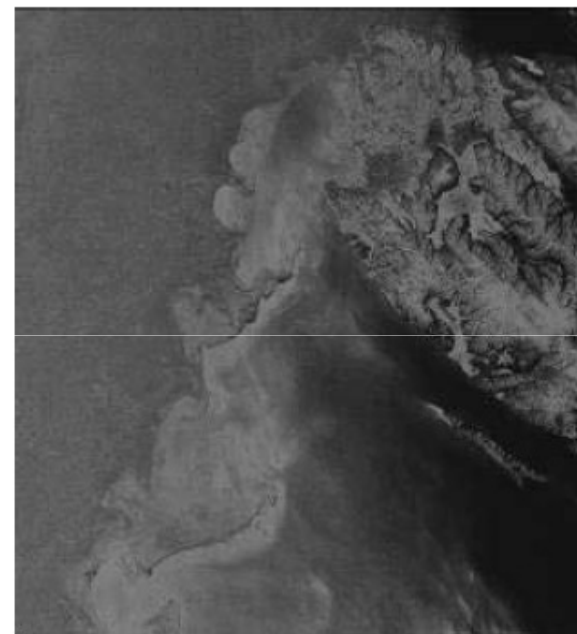
→ dark



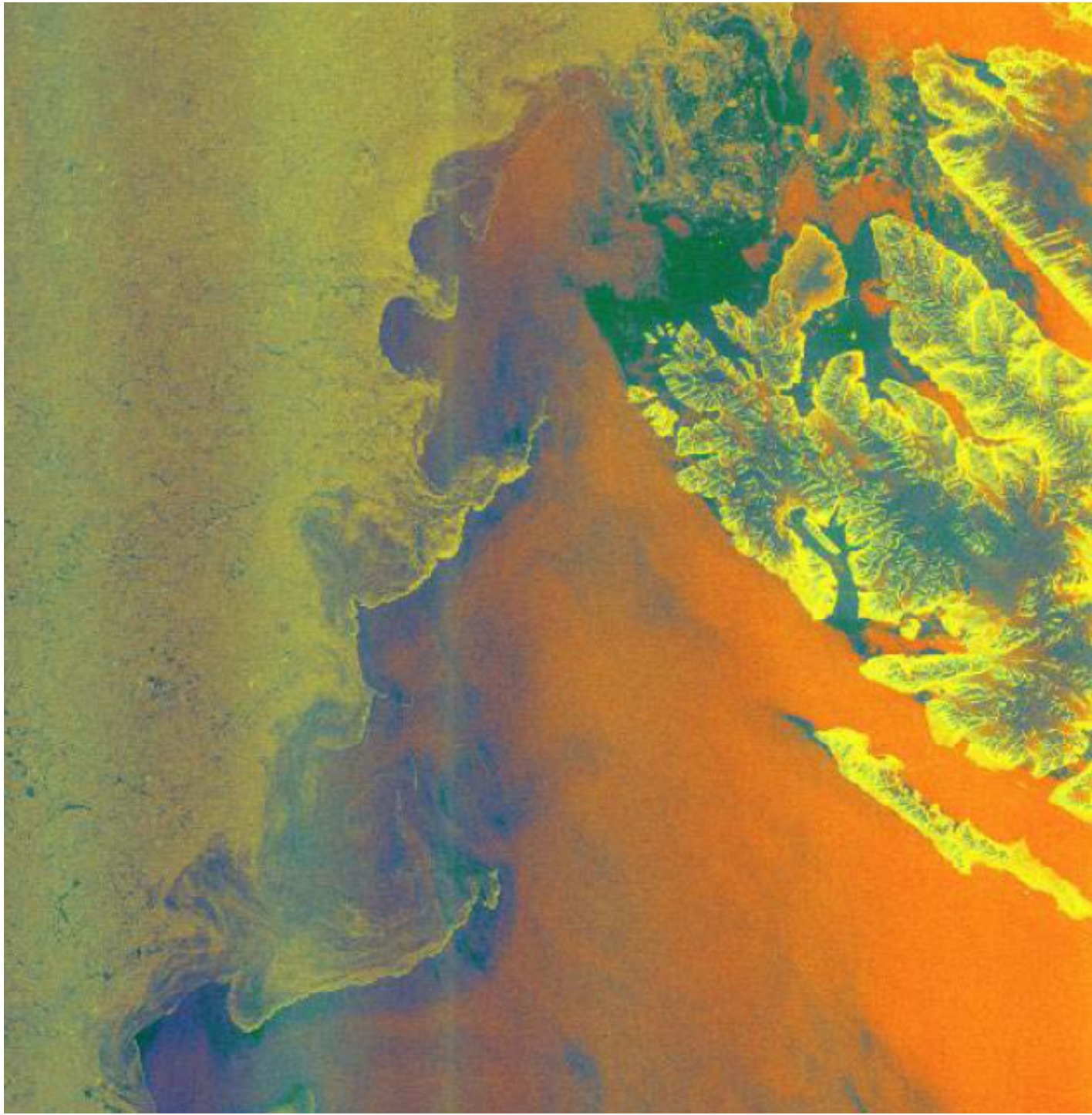
HH



HV

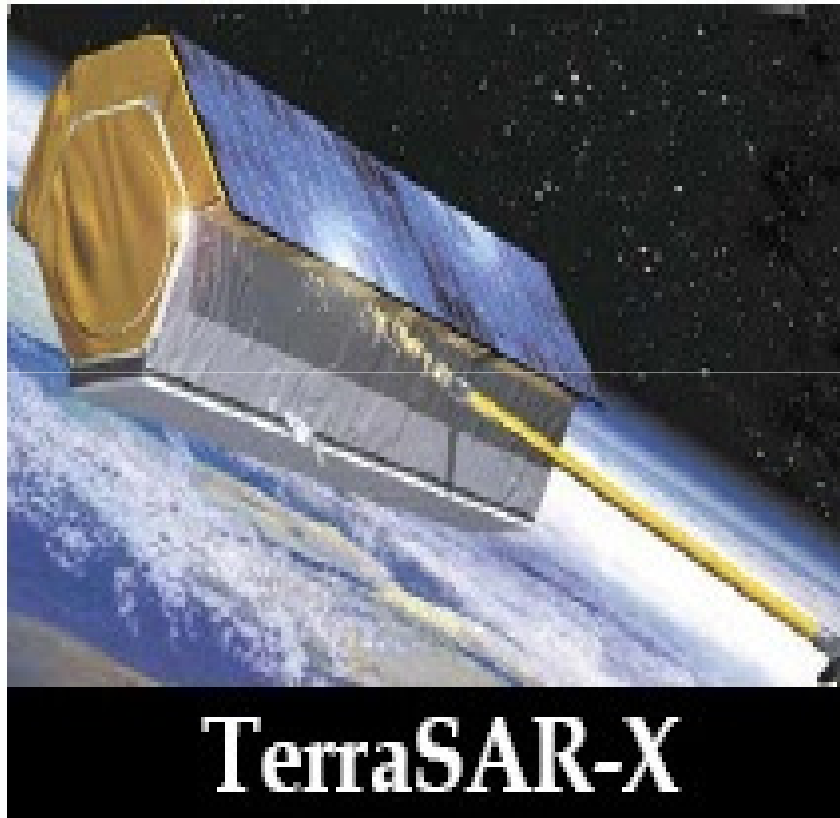


HV-HH



R=HH
G=HV
B=HV-HH

Novejše naprave SAR



Microsoft PowerPoint - [MBTL_SAR_DLR_STG_070117]

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Type a question for help

Times New Roman 24 B I U S

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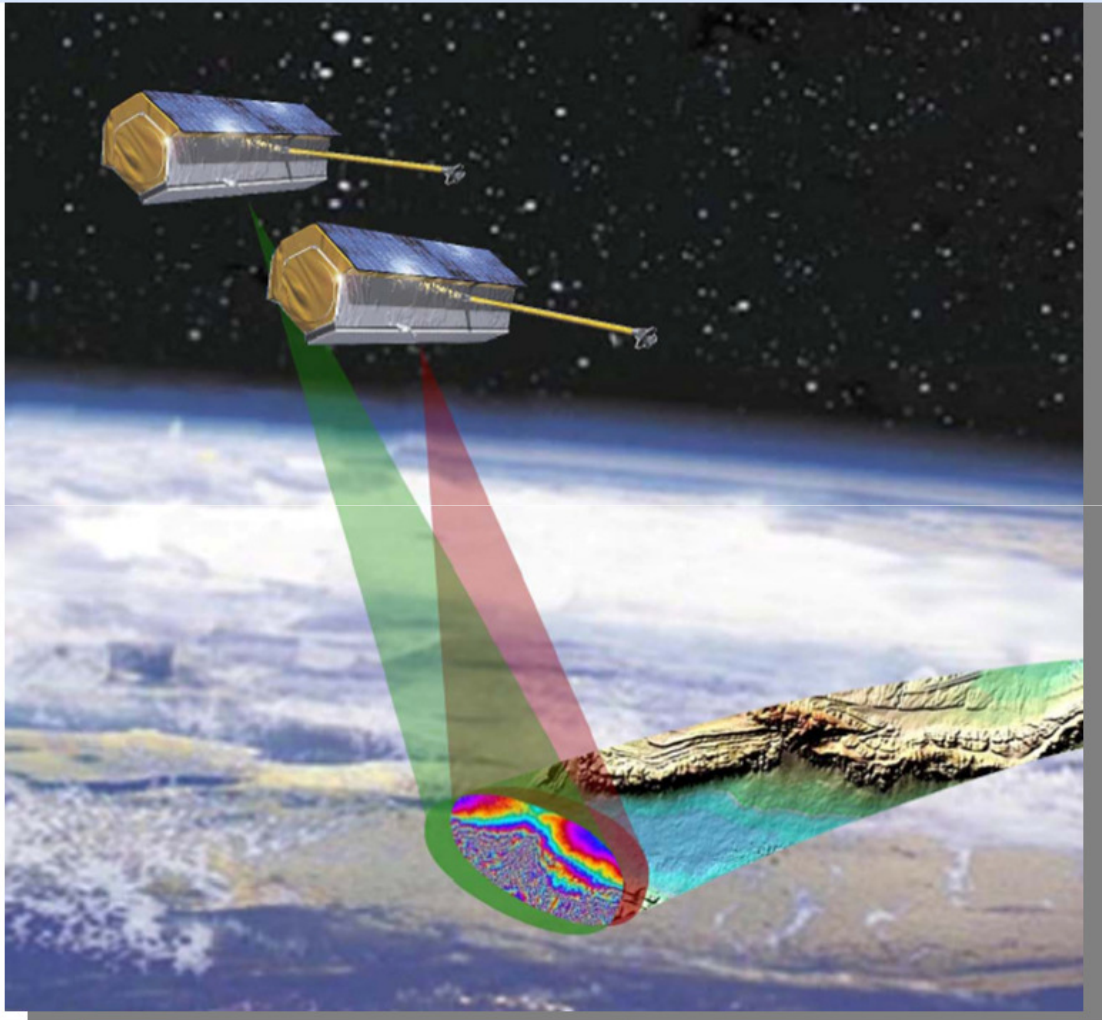
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Slide 8 of 21 Standarddesign Slovenian

start MBTL_POLAR_Presen... MBTL_SAR_16.10_shi... MBTL_SAR_DLR_STG... My Documents SL 20:39

The image shows a Microsoft PowerPoint slide titled "TerraSAR-X" with the subtitle "t as TerraSAR-X". The slide features a large image of two TerraSAR-X satellites in orbit over Earth, with a 3D SAR image of a coastal area. The slide is part of a presentation titled "MBTL_SAR_DLR_STG_070117". The slide number is 8 of 21. The presentation is in Slovenian. The system tray shows the date and time as 20:39.