# Spaceborne SAR Systems for Polarimetric, Interferometric and PolinSAR Applications


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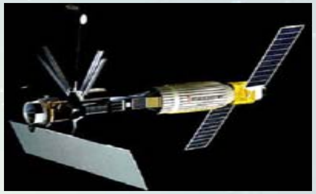
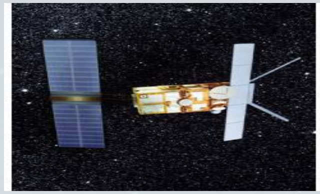
# Spaceborne SAR Systems



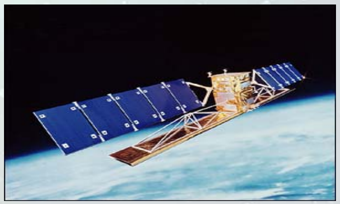
## SEASAT
NASA/JPL (USA)
L-Band, 1978



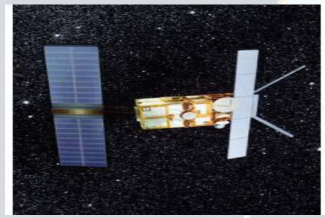
## ERS-1
European Space Agency (ESA)
C-Band, 1991-2000

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

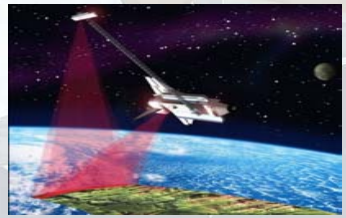
## SIR-C/X-SAR
NASA/JPL, L- and C-Band (quad)
DLR / ASI, X-band
April and October 1994



## RADARSAT-1
Canadian Space Agency (CSA)
C-Band, 1995-today

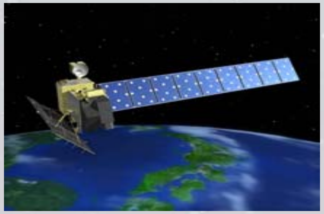


## ERS-2
European Space Agency (ESA)
C-Band, 1995-today

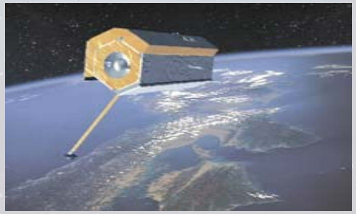


## SRTM
NASA/JPL (C-Band), DLR (X-Band)
February 2000

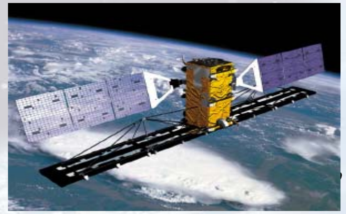
## ENVISAT / ASAR
European Space Agency (ESA)
C-Band (dual), 2002-today



## ALOS / PALSAR
Japanese Space Agency (JAXA)
L-Band (quad), 2005



## TerraSAR-X
German Aerospace Center (DLR) / Astrium
X-Band (quad), 2006

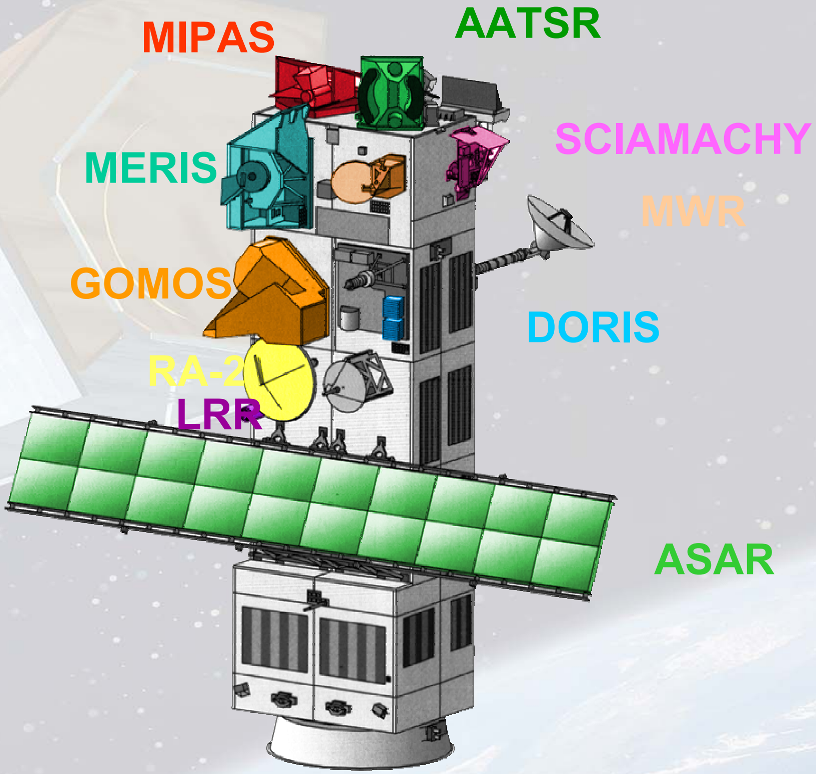


## RADARSAT-II
Canadian Space Agency (CSA)
C-Band (quad), 2006

## CosmoSkymed
ASI / Alenia
X-Band (dual), 2006

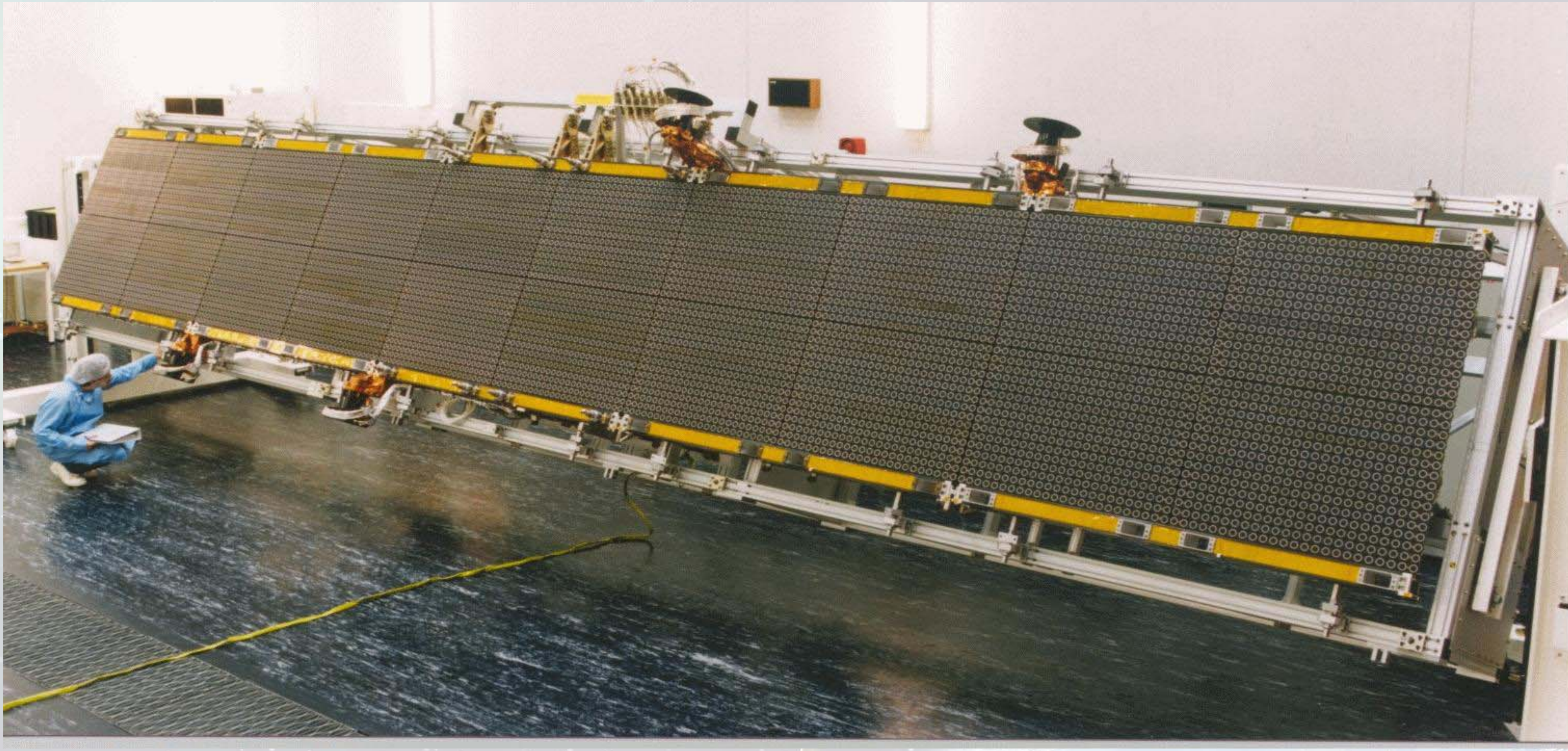
# ENVISAT/ASAR

# ESA's ENVISAT


- Most ambitious Remote Sensing satellite for environmental monitoring
- Unique combination of 10 instruments

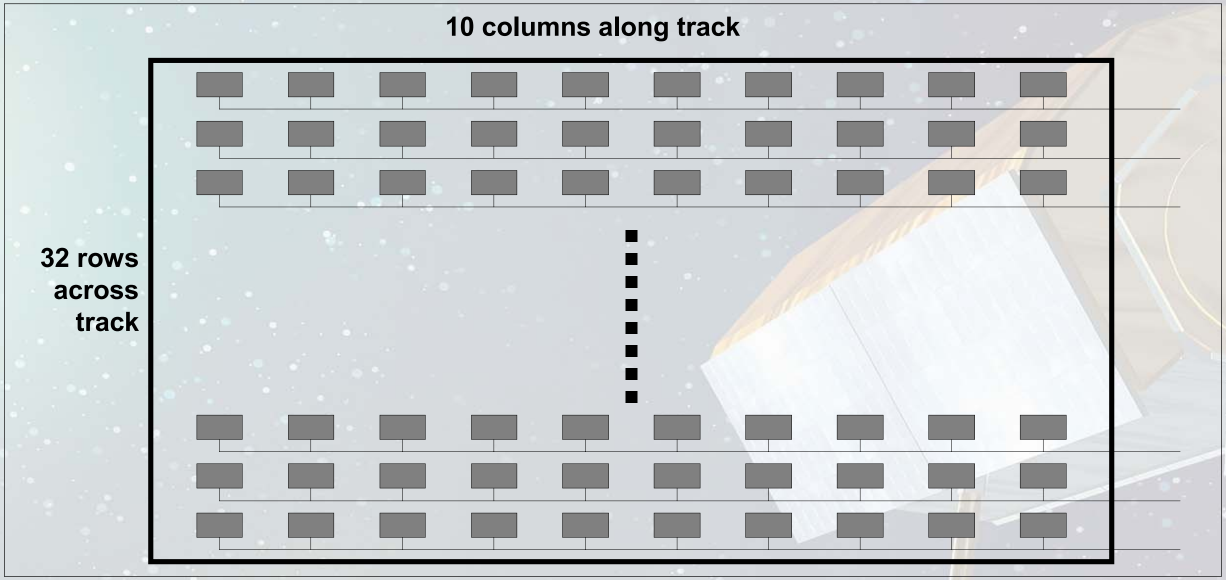
# Active Phased Array Antenna

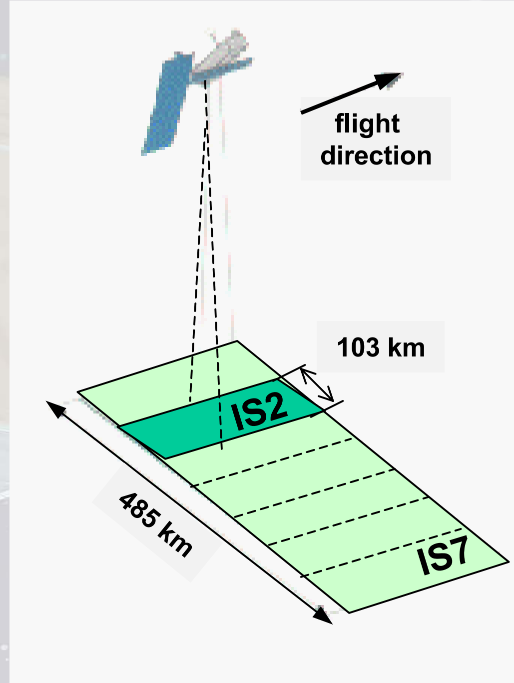


**ASAR Antenna consisting of 320 Transmit/Receive Modules in 32 rows and 10 elements per row**

# ASAR Operation Modes

ASAR-Antenna (ca. 10 m x 1.33 m and 320 T/R-Modules)

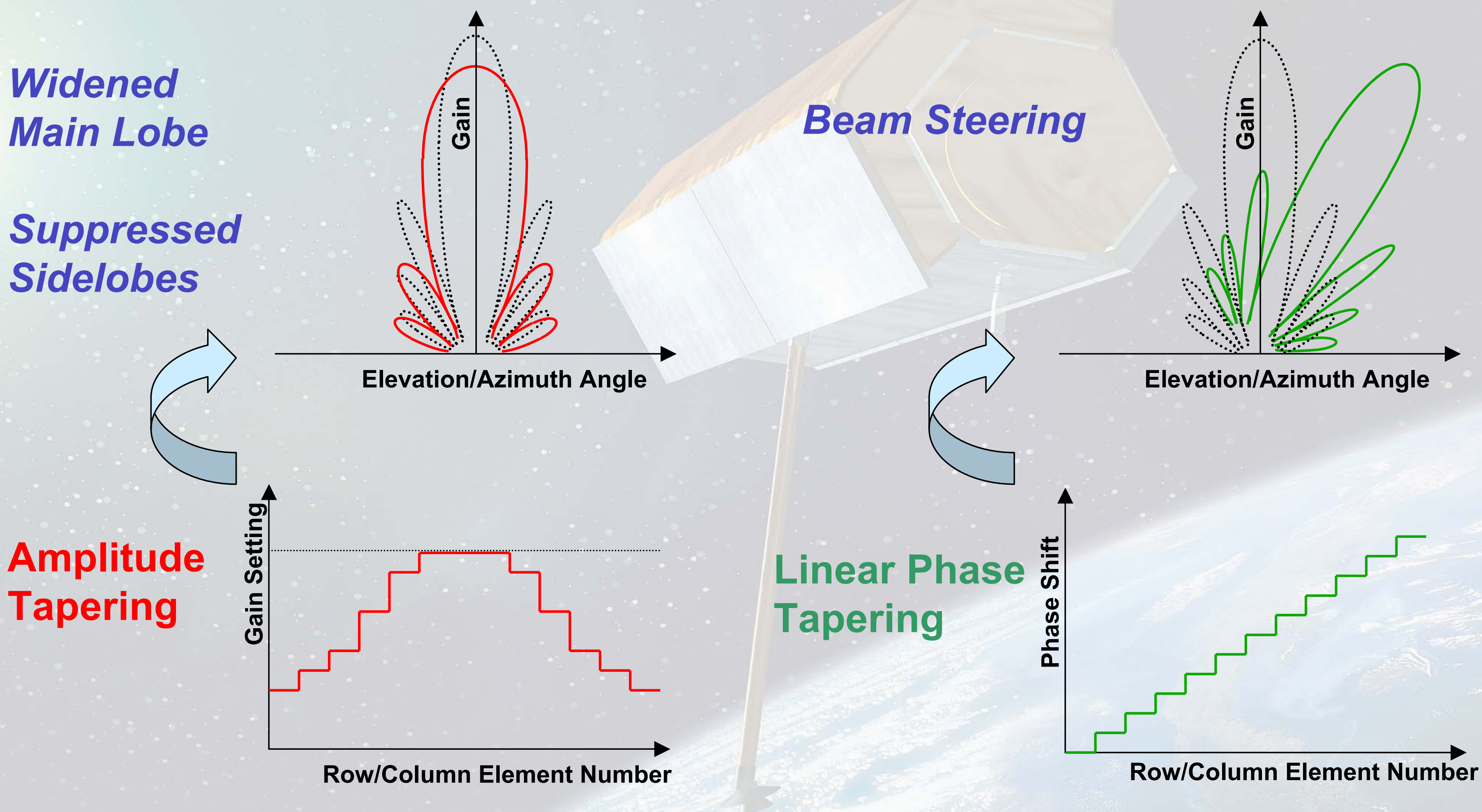


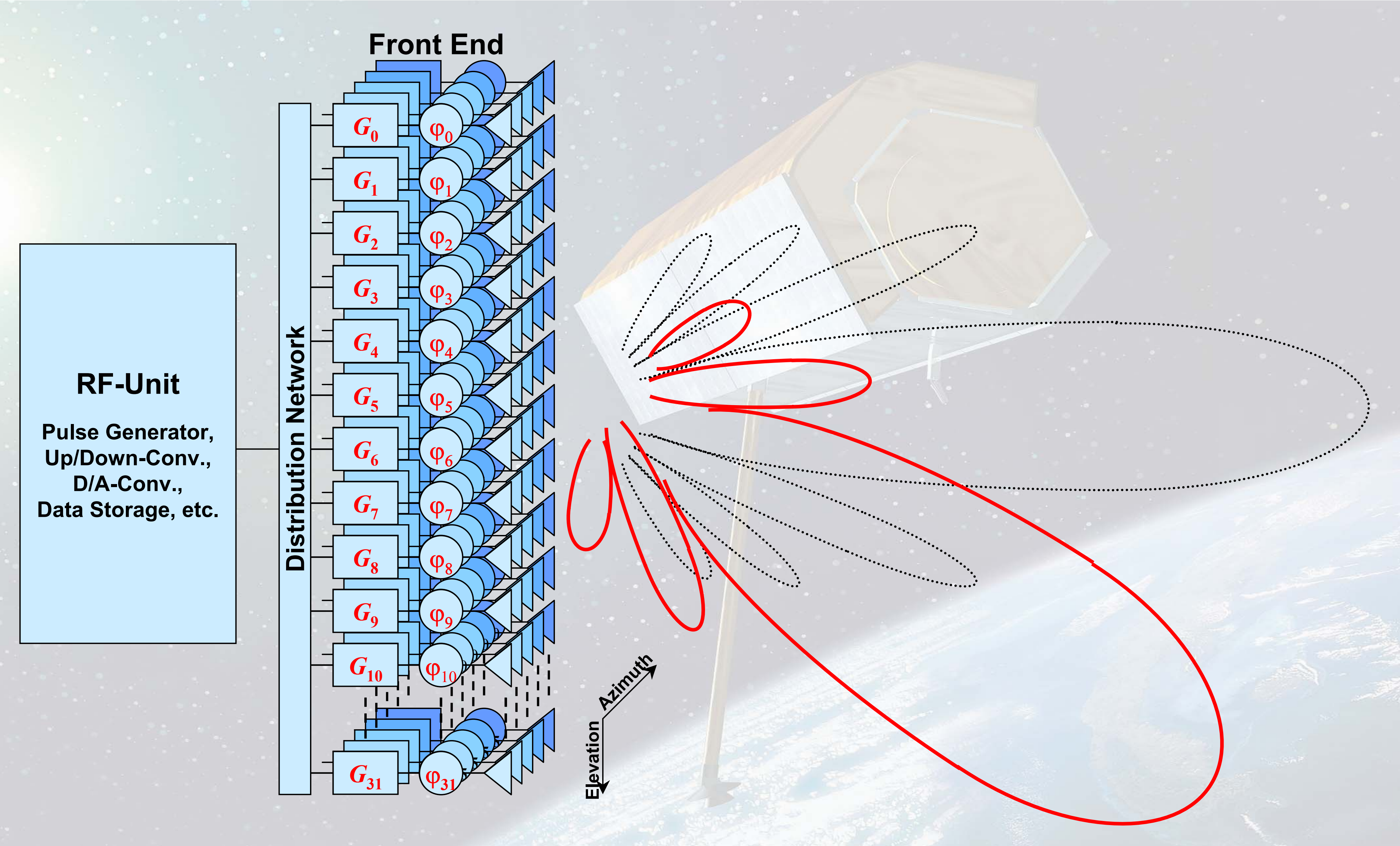

ASAR imaging modes

| | IS 1 | IS 2 | IS 3 | IS 4 | IS 5 | IS 6 | IS 7 |
|---|---|---|---|---|---|---|---|
| PRF [Hz] | 1678 | 1645 | 2096 | 1680 | 2082 | 1698 | 2097 |
| ASAR center look angle | 16.6° | 20.1° | 25.2° | 29.5° | 32.8° | 35.6° | 38.0° |
| ASAR swath width in ground range [km] | 103.7 | 103.3 | 82.3 | 88.6 | 64.5 | 71.0 | 56.7 |

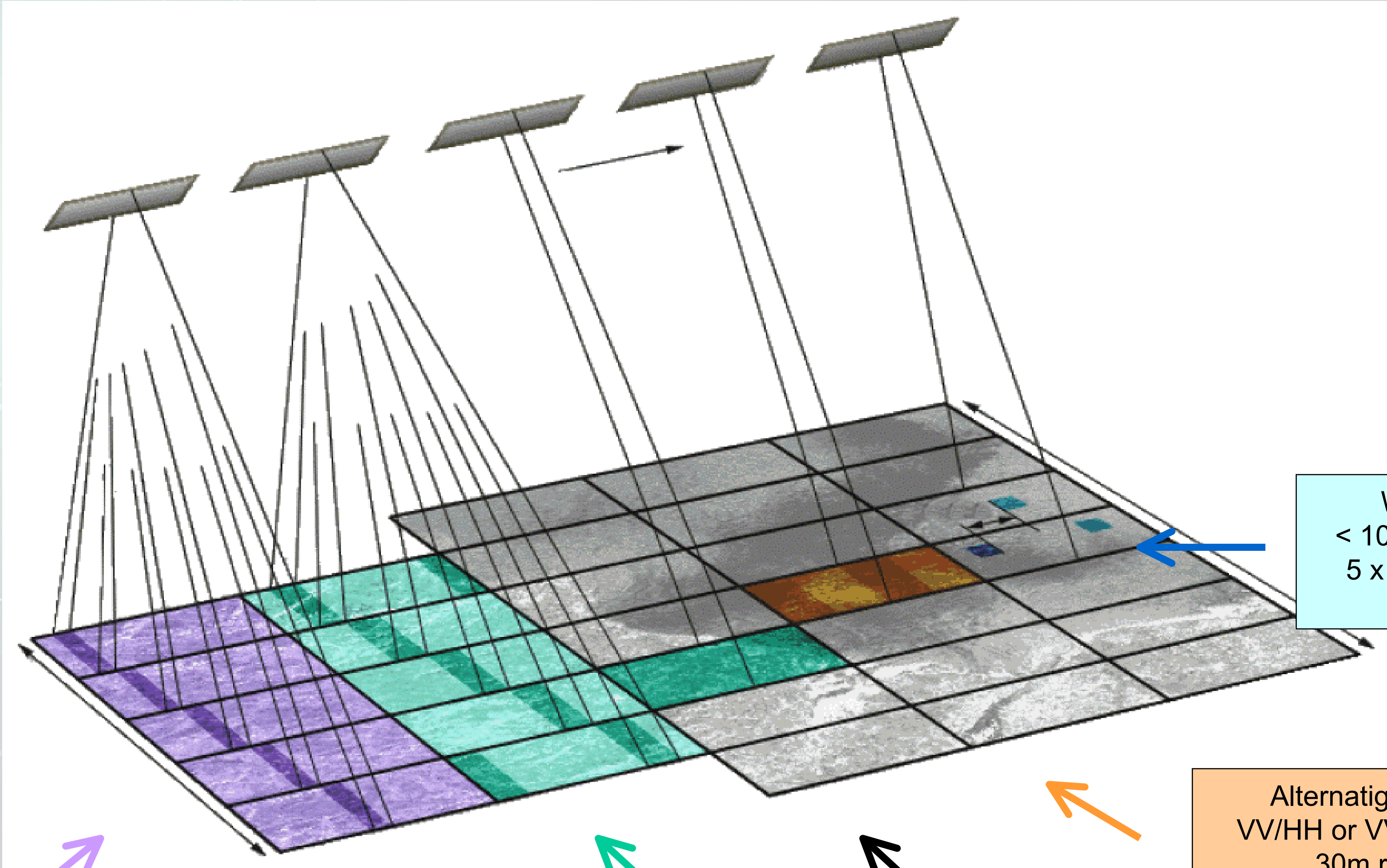
# *Electronic Beam Forming*



# Electronic Beam Forming



# ASAR Operation Modes



Wave VV or HH
< 10m resolution (SLC)
5 x 5 km to 10 x 5 km
vignettes

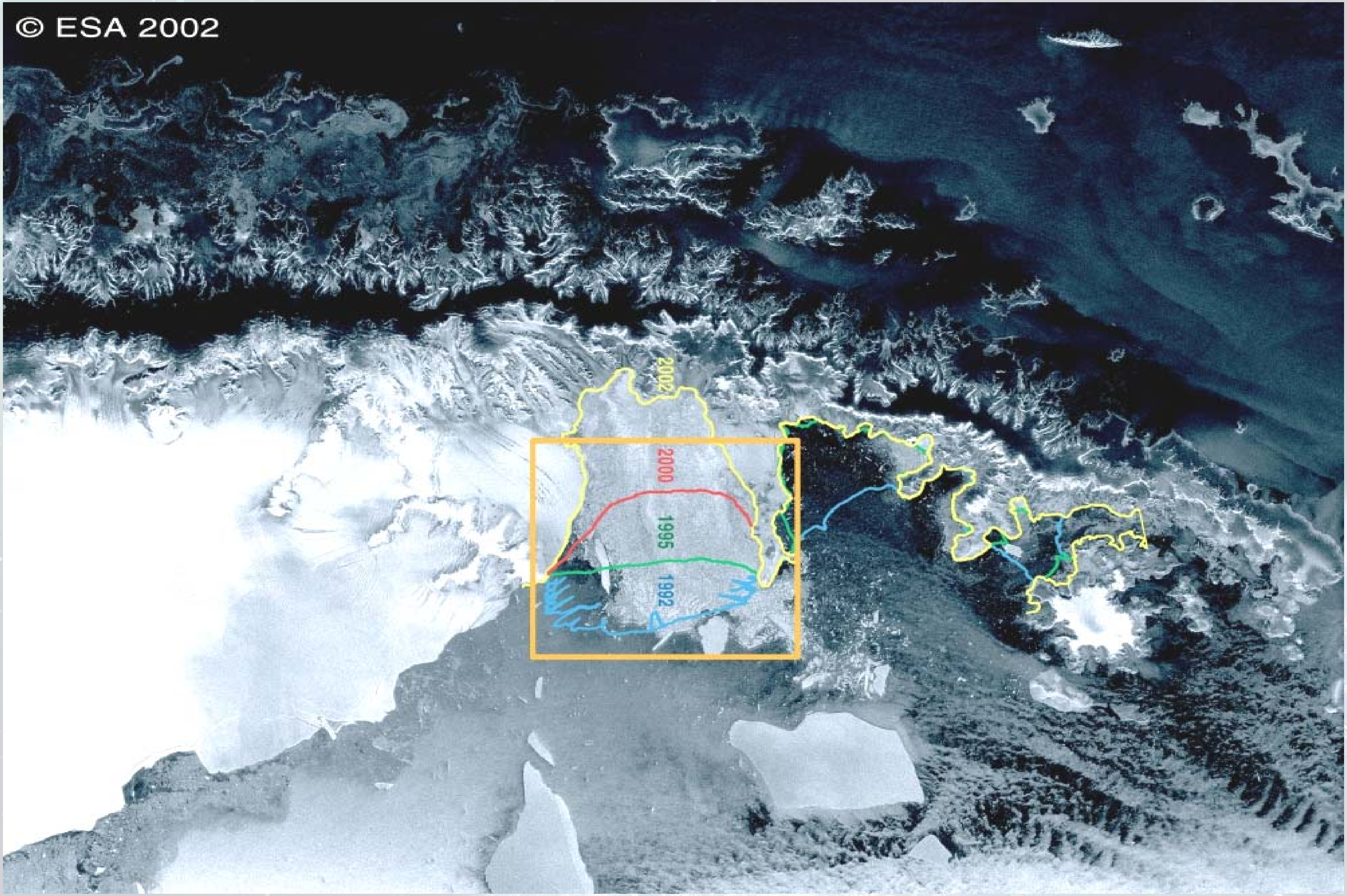
Alternatig Polarisation
VV/HH or VV/VH or HH/HV
30m resolution
up to 100 km swath

Global Monitoring
VV or HH
1000m resolution
405 km swath width

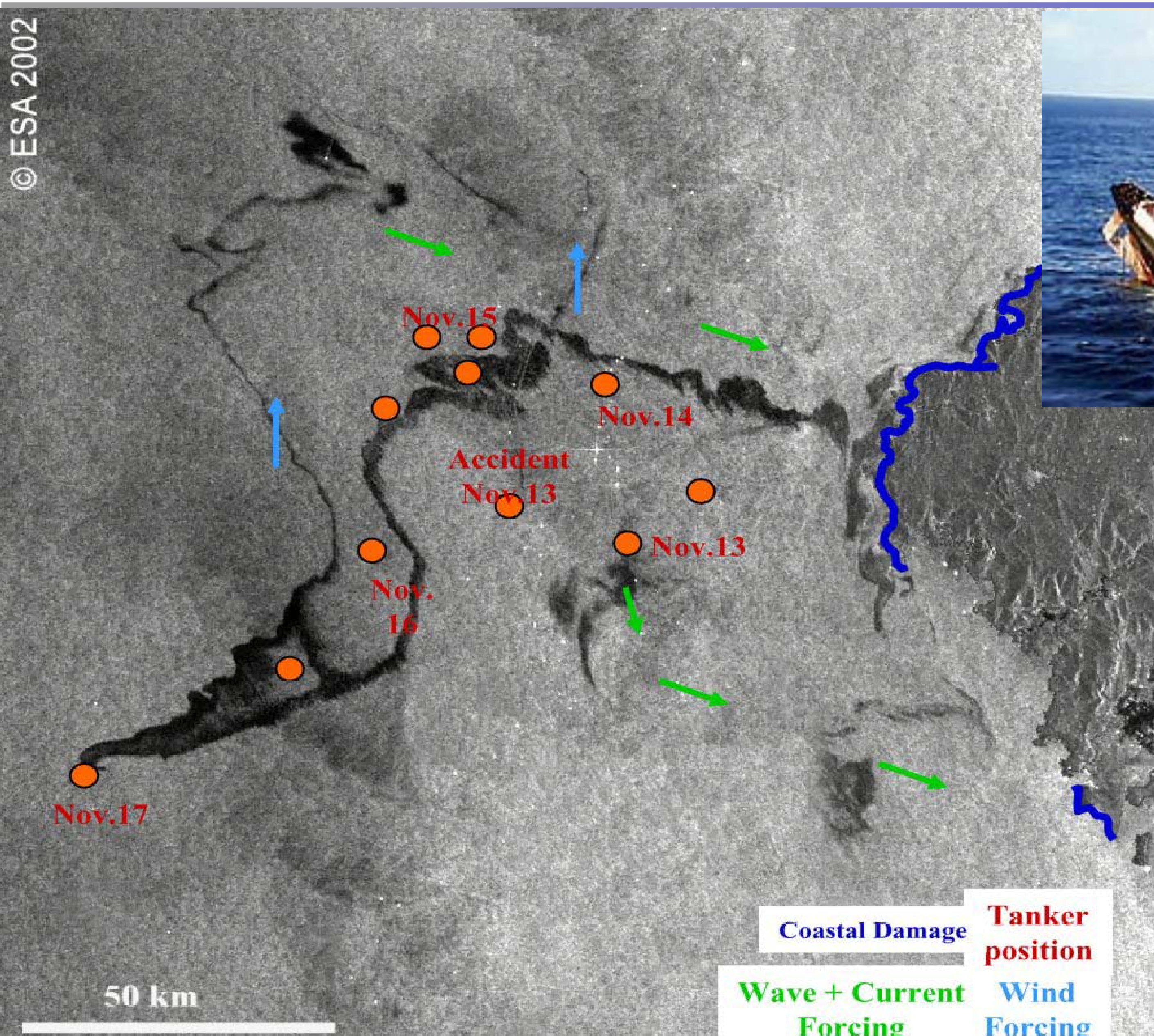
Wide Swath
VV or HH
150m resolution
405 km swath width

Image VV or HH
< 30m resolution
up to 100 km swath

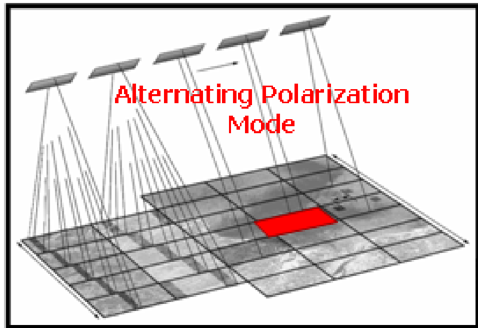
# ENVISAT ASAR: First Image Example



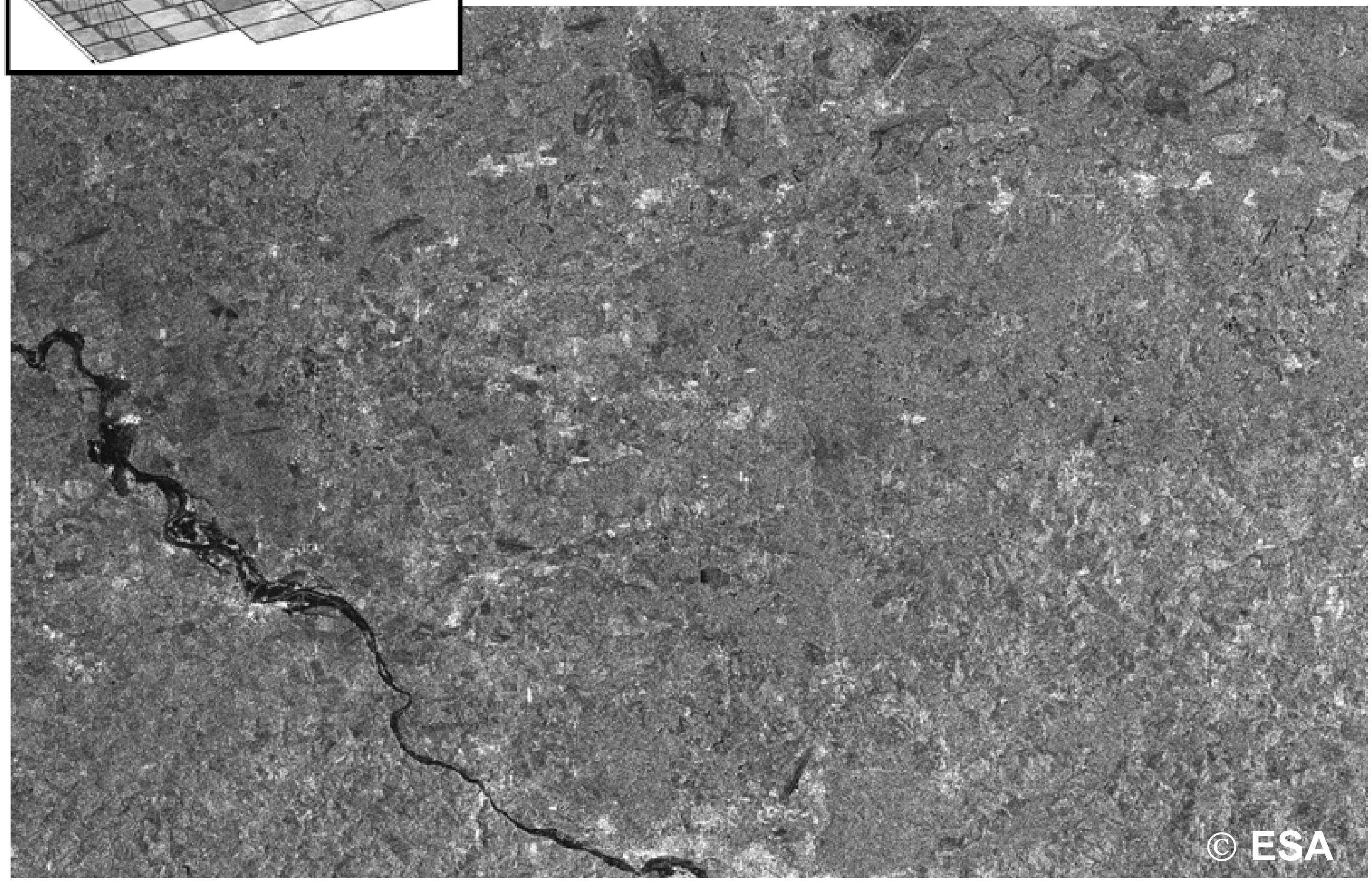
# Oil Detection with ASAR




# Single-Pol versus Polarimetric ASAR Image



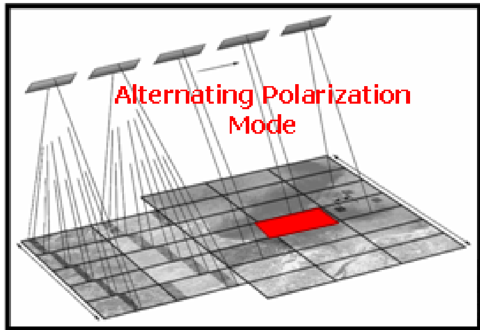

**German flood event (Summer 2002)**
ASAR Alternating Polarization mode



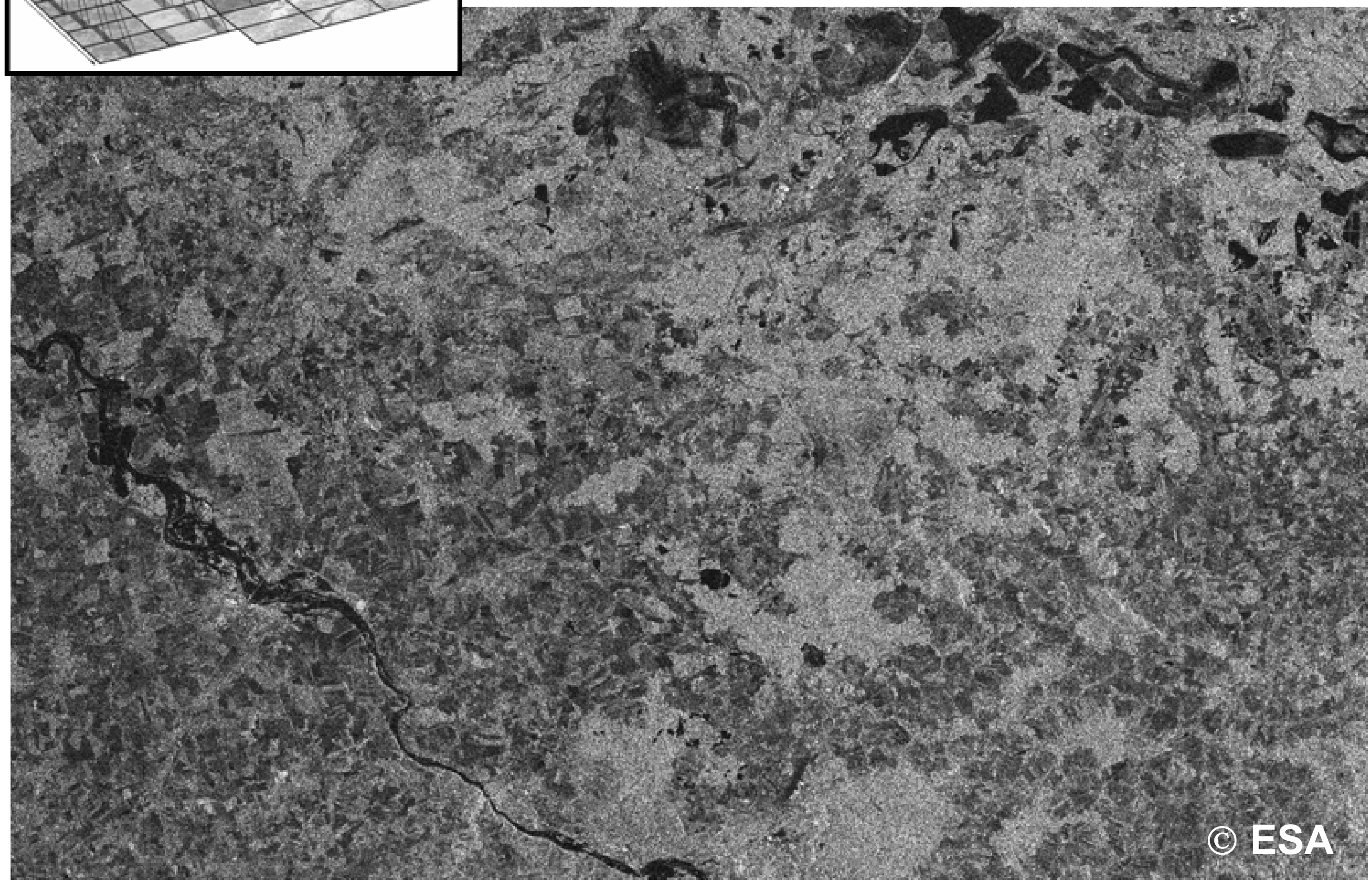

HH

swath IS2
19 August 02

# Single-Pol versus Polarimetric ASAR Image



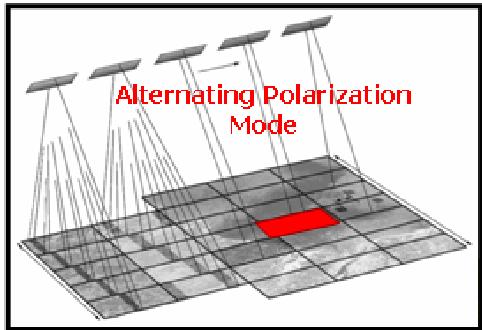

German flood event (Summer 2002)
ASAR Alternating Polarization mode




HV

swath IS2
19 August 02

# Single-Pol versus Polarimetric ASAR Image




**German flood event (Summer 2002)**
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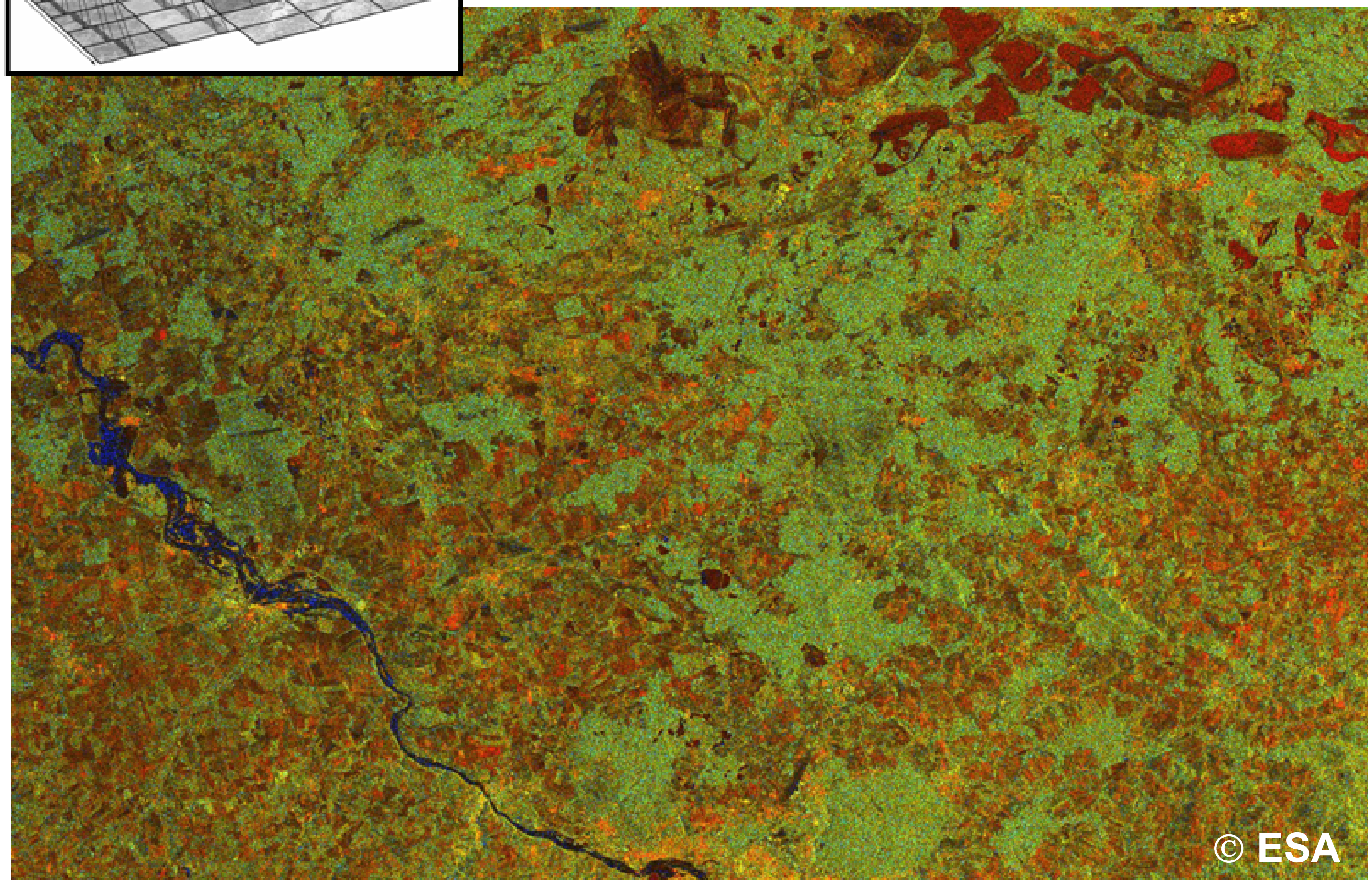


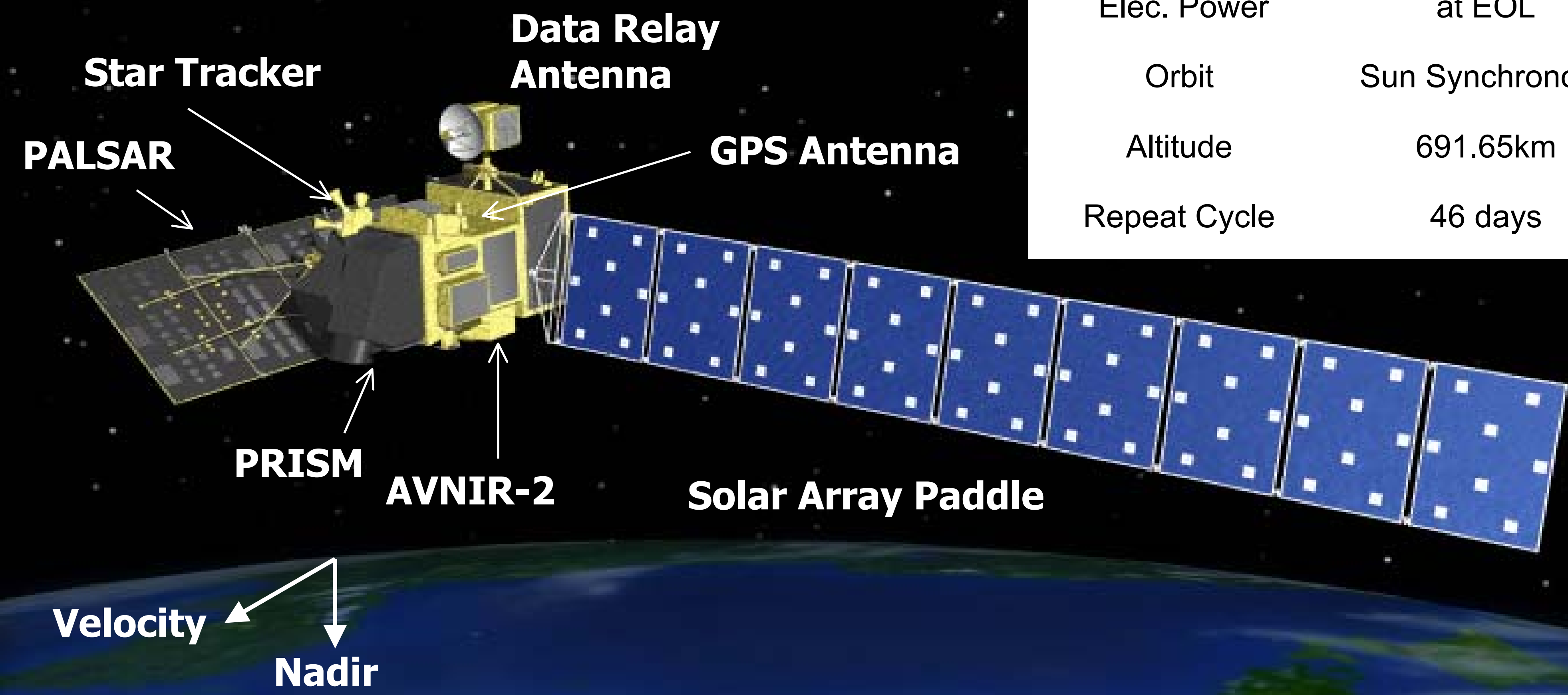

HH
HV
HH-HV

swath IS2
19 August 02

# *ALOS/PALSAR*

# *ALOS Satellite System*

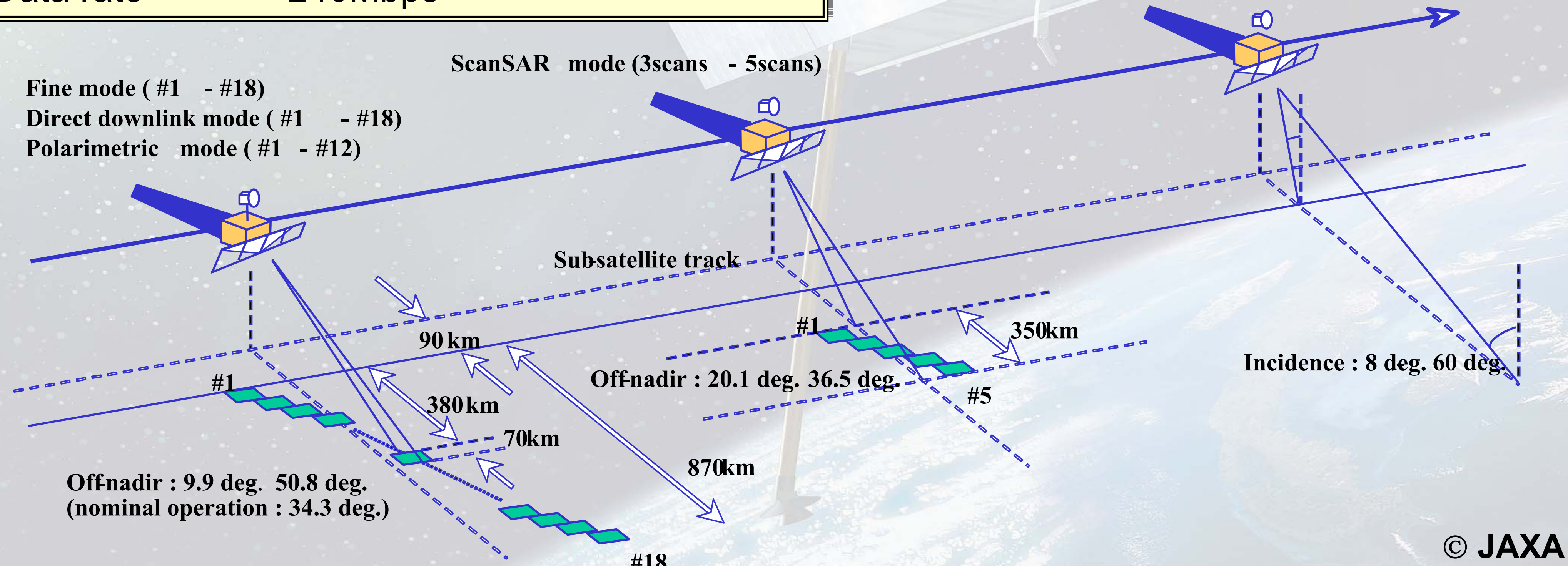
| | |
|---|---|
| Launch Date | September 2005 |
| Launch Vehicle | H-IIA |
| Spacecraft Mass | about 4,000kg |
| Generated Elec. Power | about 7kW at EOL |
| Orbit | Sun Synchronous |
| Altitude | 691.65km |
| Repeat Cycle | 46 days |




**PRISM: Panchromatic Remote-sensing Instrument for Stereo Mapping**
**AVNIR-2: Advanced Visible and Near Infrared Radiometer type 2**
**PALSAR: Phased Array type L-band Synthetic Aperture Radar**

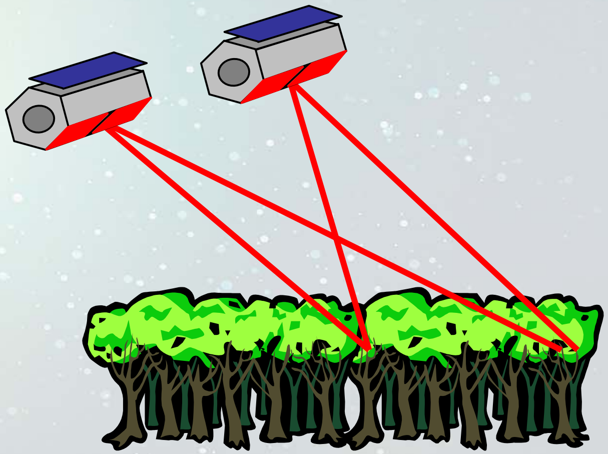
# ALOS / PALSAR

| | |
|---|---|
| Frequency | 1270 MHz |
| Band Width | 28/14MHz |
| Modes | FBS,FBD,POL, SCAN |
| Antenna beams | 18 (STRIP)+5 SCANs |
| Image Width | 70Km |
| Incidence | 7.7 - 60 degrees |
| Tr. power | 2Kw |
| Resolution | 9m(2L) |
| Data rate | 240Mbps |



# Single Pass
# Polarimetric SAR Interferometry

## *Pol-InSAR*



Observables

***3 Interferometric Coherences***

***3 Interferometric Phases***

*for one baseline and three polarisation states*

**I Step:**
**Model and Validation Development**

**Coherent Scattering Model**

## *Natural Scatterers*

**Forest Parameters**

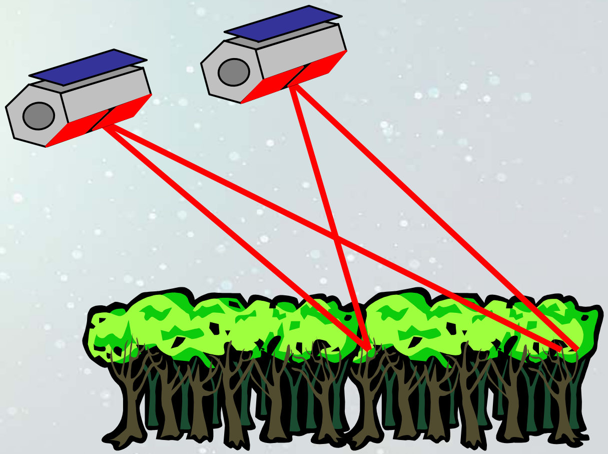
**Surface Parameters**

**Agricultural Parameters**

**Land Ice Parameters**

# Single Pass
# Polarimetric SAR Interferometry

## Pol-InSAR



Observables

***3 Interferometric Coherences***

***3 Interferometric Phases***

*for one baseline and three polarisation states*

**II Step: Model and Validation Inversion**

**Coherent Scattering Model**

## Natural Scatterers

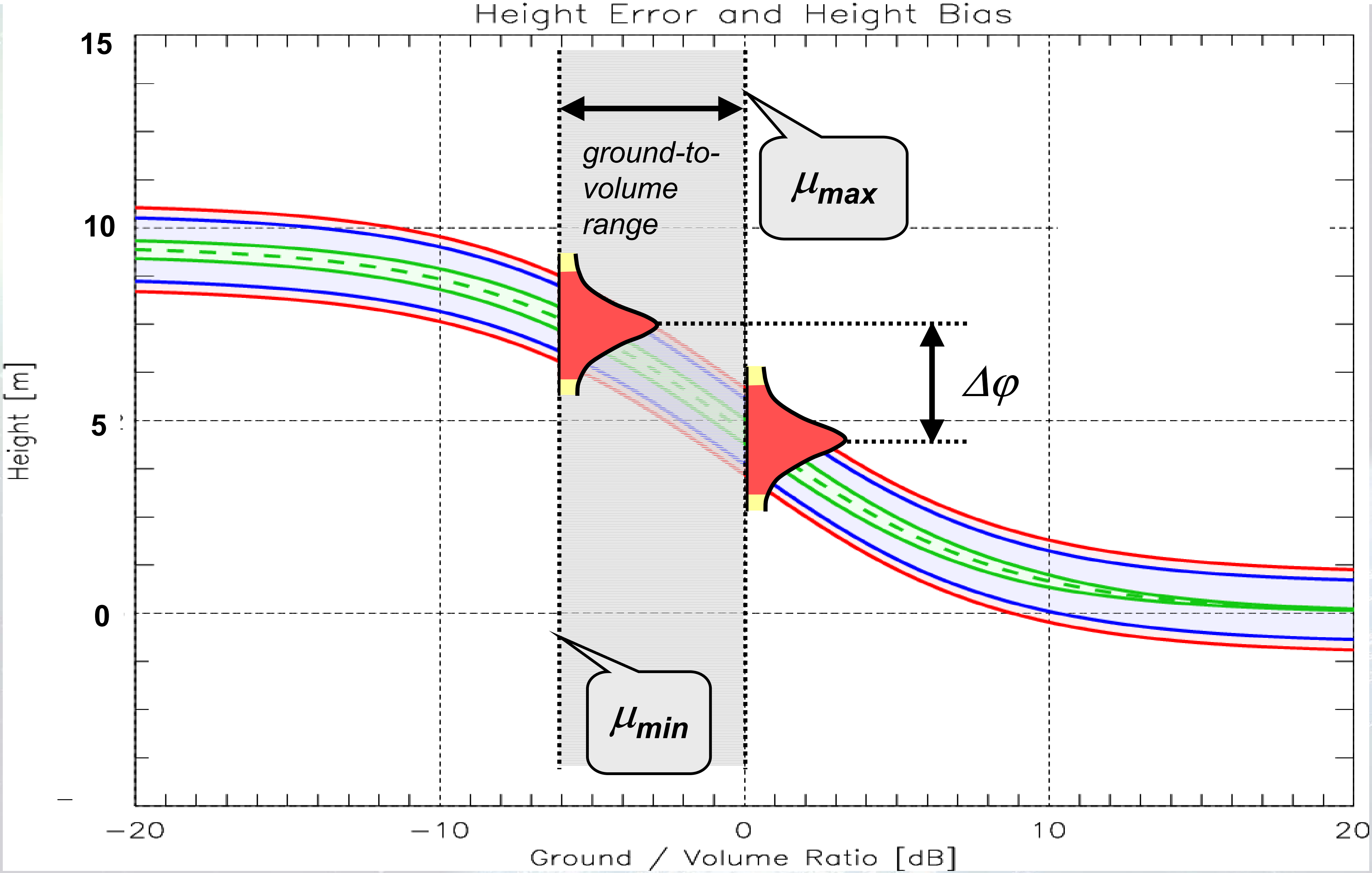
**Forest Parameters**

**Surface Parameters**

**Agricultural Parameters**

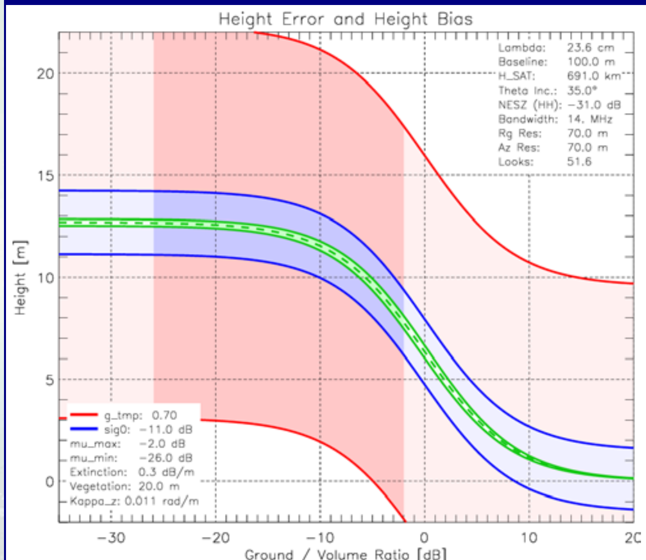
**Land Ice Parameters**

# Polarimetric Interferometric: Performance Estimation

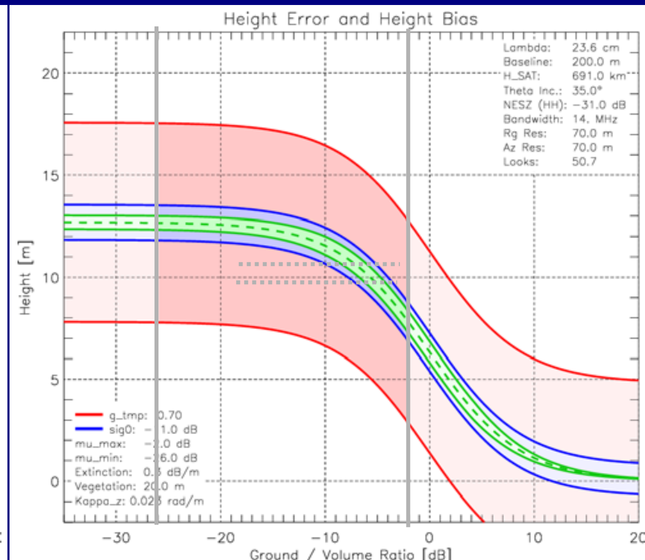


# ALOS/PALSAR ($\gamma_{tmp}$ = 0.7, 70 m x 70 m)

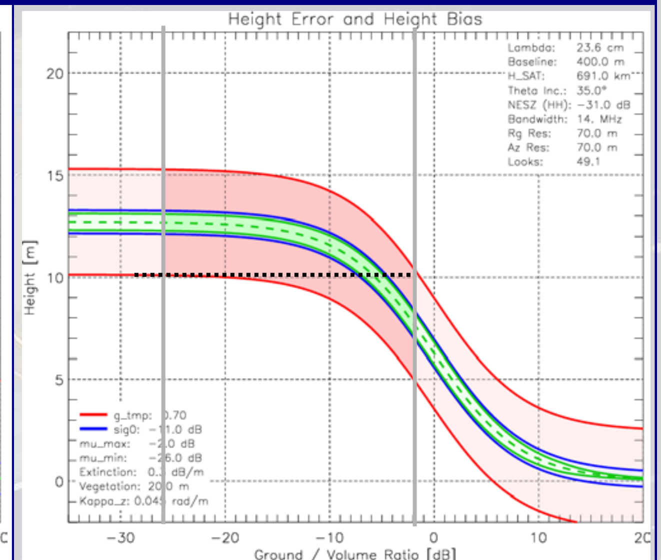
## B = 100 m



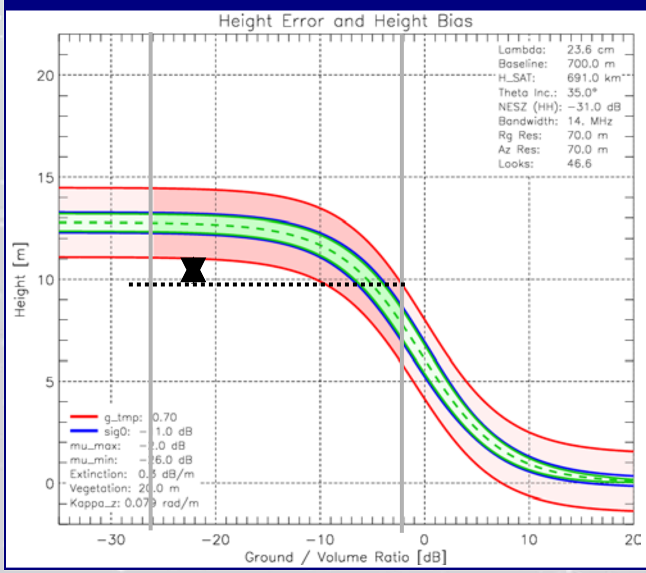

## B = 200 m



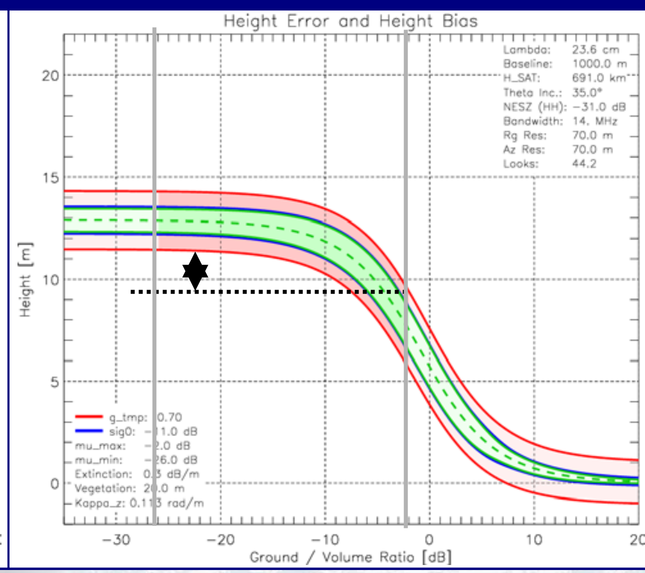

## B = 400 m



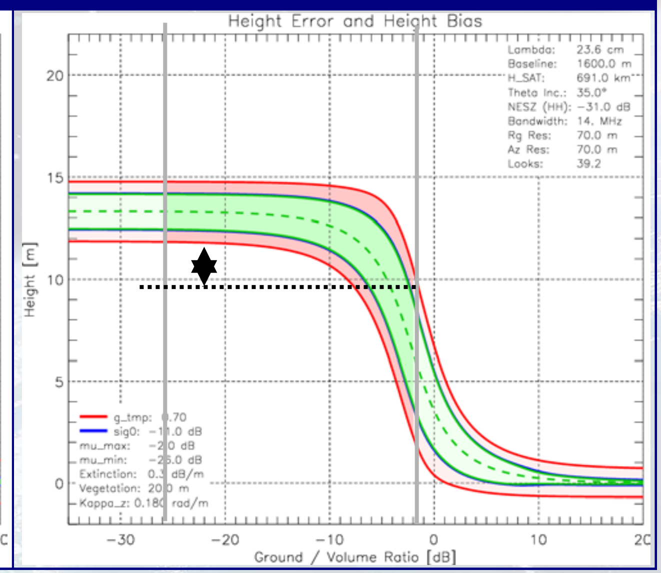

## B = 700 m



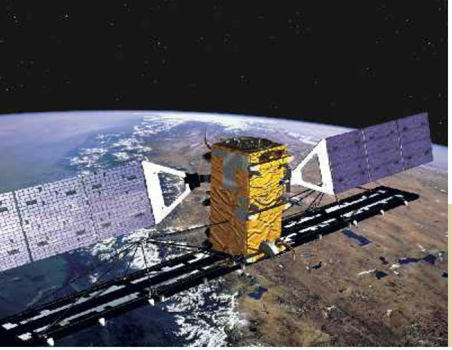

## B = 1000 m




## B = 1600 m

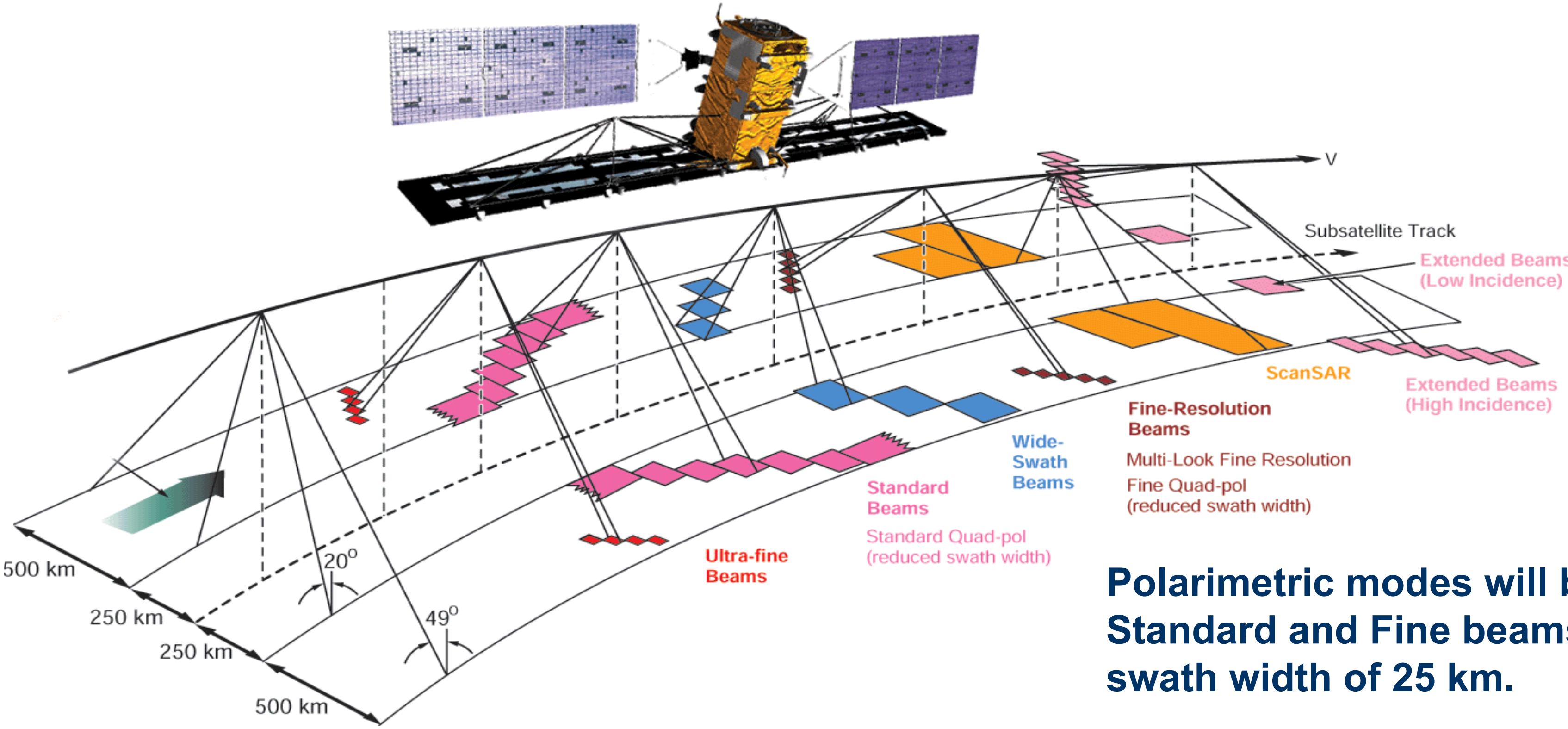


# RADARSAT-II



# R A D A R S A T - 2

## RADARSAT-2 Imaging Modes




**Polarimetric modes will be available on Standard and Fine beams with a limited swath width of 25 km.**

**All modes will be available in selective single or dual polarization.**

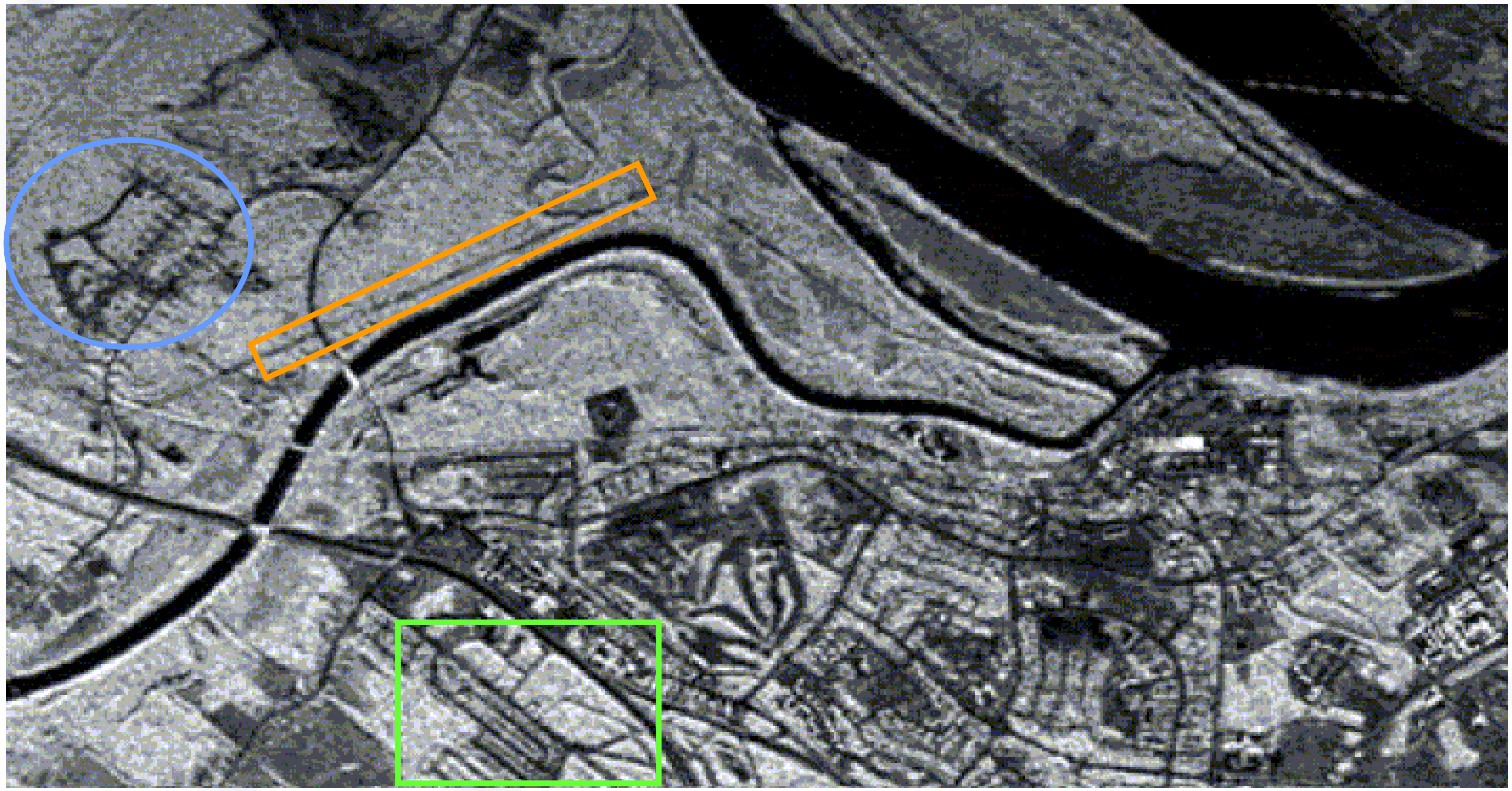
**All modes will be available on either side of the satellite.**

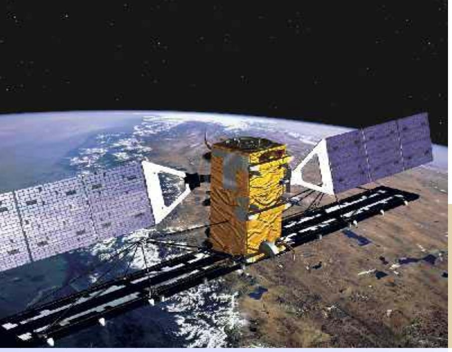
MACDONALD DETTWILER®

# R A D A R S A T - 2

## Ultra-fine Imaging

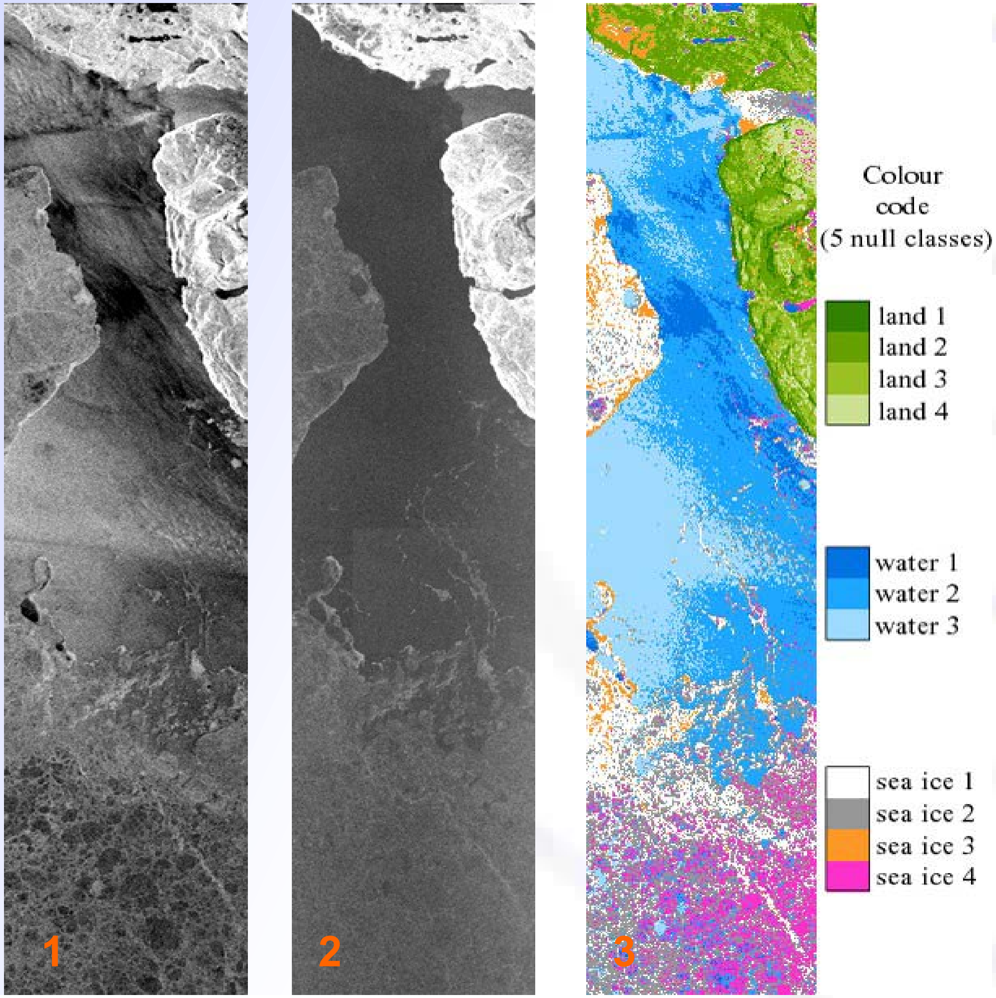
**Comparison between RADARSAT-1 Fine beam (10 m resolution) and simulated RADARSAT-2 Ultra-fine beam (3 m resolution)**





# RADARSAT-2

## Polarimetric Application: Sea Ice




1- HH polarization image showing enhanced ice-type information.

2- HV polarization image showing enhanced ice-edge information.

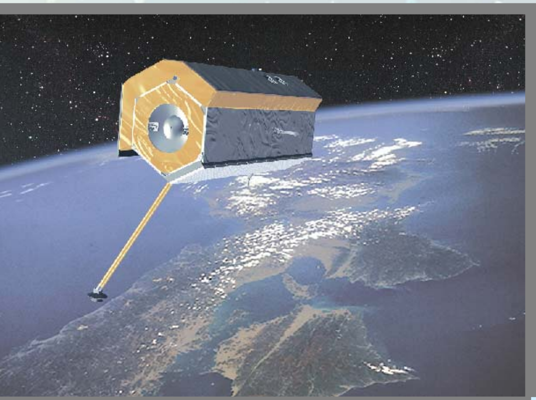
3- H/A/$\alpha$ Maximum Likelihood classification results after five iterations.

**Data acquired from C-band Shuttle Imaging Radar (SIR) of the west coast of Newfoundland, April, 1994.**

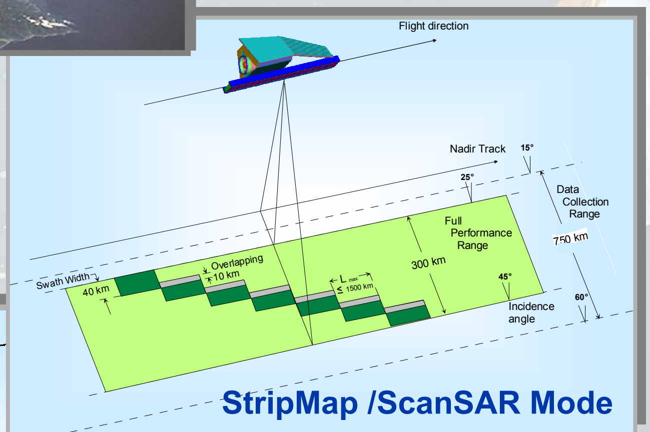
**Study performed by MDA through the Earth Observation Application Development Program (EOADP) of the the Canadian Space Agency.**

# TerraSAR-X

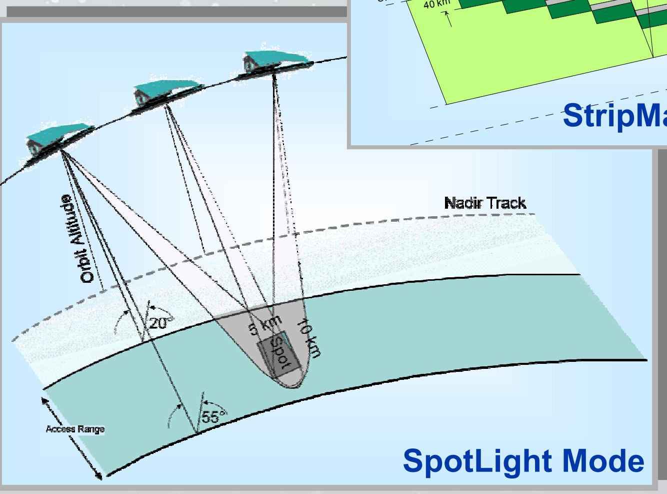
# TerraSAR-X



Start: 2006

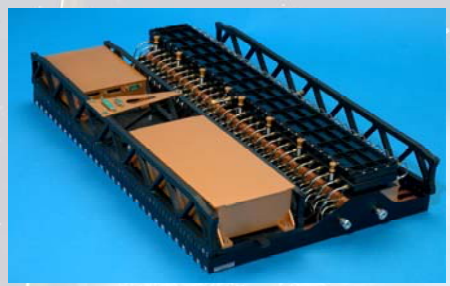


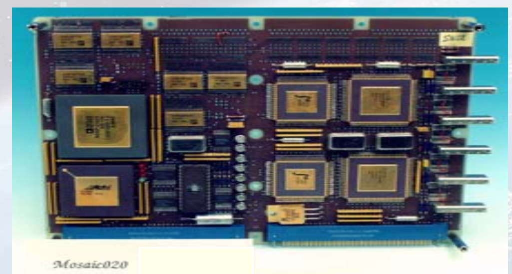

StripMap /ScanSAR Mode




SpotLight Mode

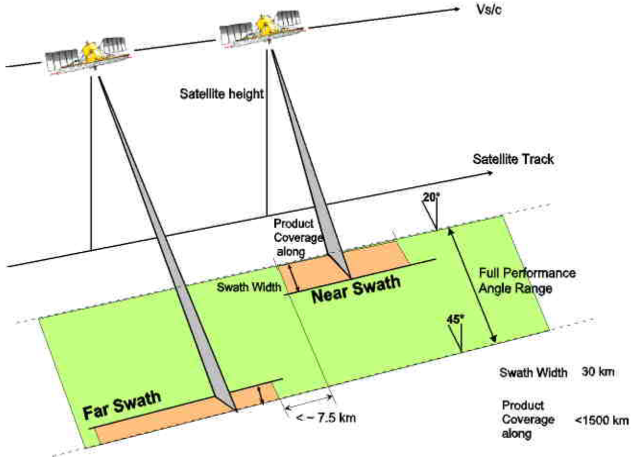
- Private Public Partnership between DLR and ASTRIUM
- Goal is to establish a sustainable Global EO information service
- Technology demonstrators:
  - DESA: X-Band Front-End Demonstrator
  - TOPAS: on-board SAR Processing and Storage Demonstrator (1999-2002)





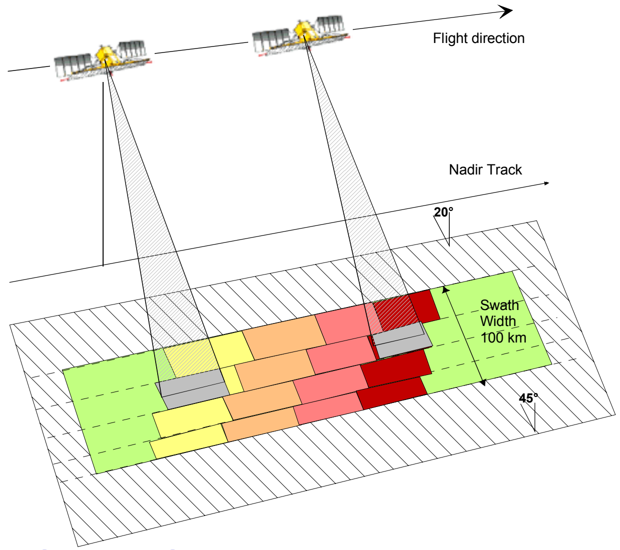

- Continuation of a successful X-Band technology program in Germany

# TerraSAR-X Imaging Modes



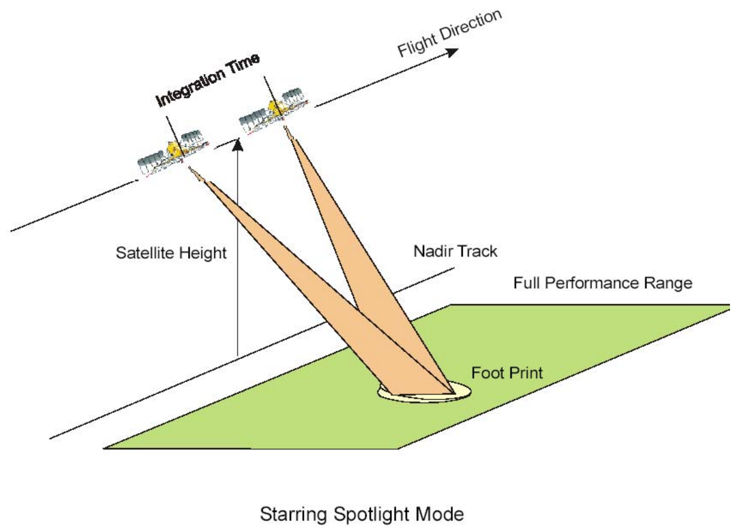

### *Strip Map Mode*

**Resolution: 3 m × 1,5 m ... 3,5 m**
**Scene Size: 100 km × 30 km**




### *Scan SAR Mode*

**Resolution: 3 m × 1,5 m ... 3,5 m**
**Scene Size: 100 km × 100 km**




### *Spotlight Mode*

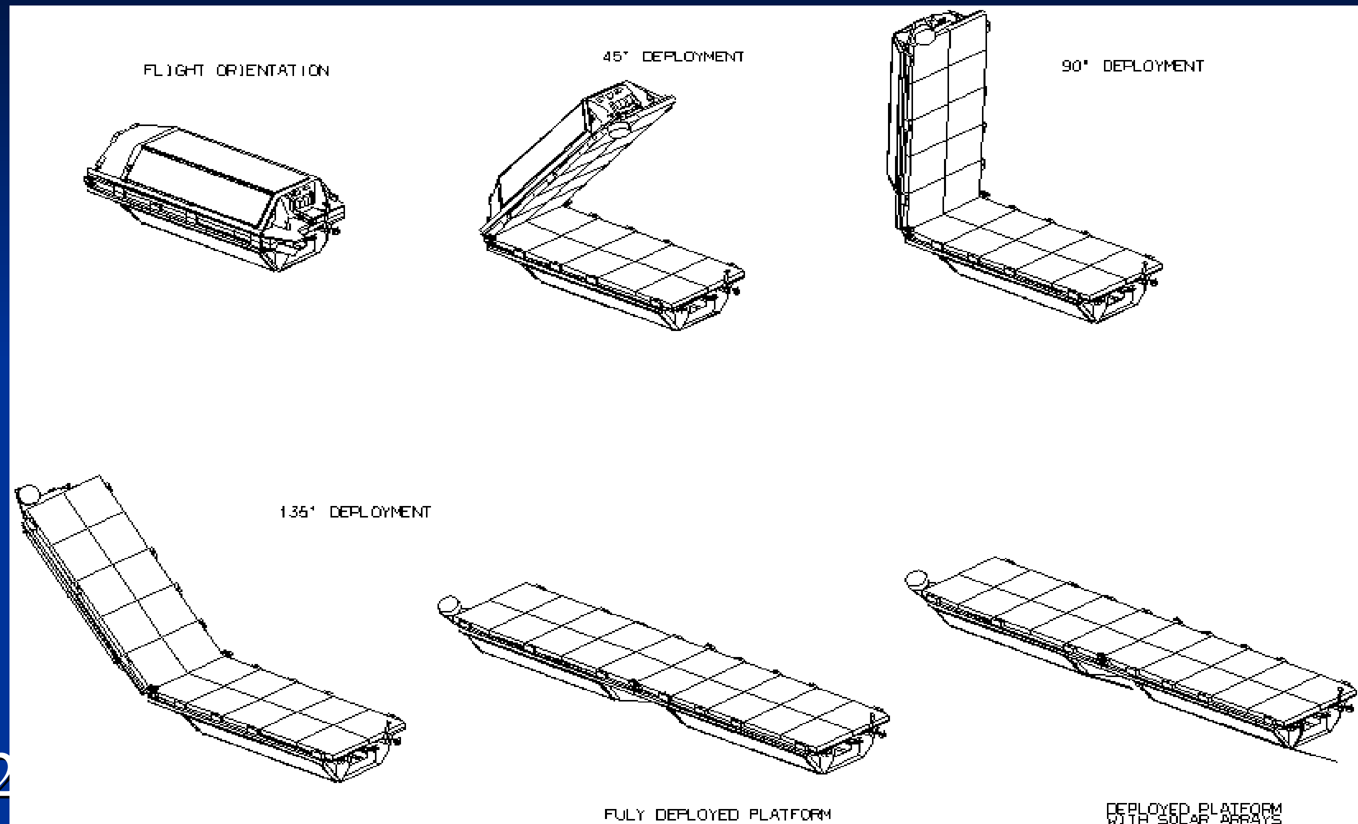
**Resolution: 1 m × 1,5 m ... 3,5 m**
**Scene Size: 5 km...10 km × 10 km**

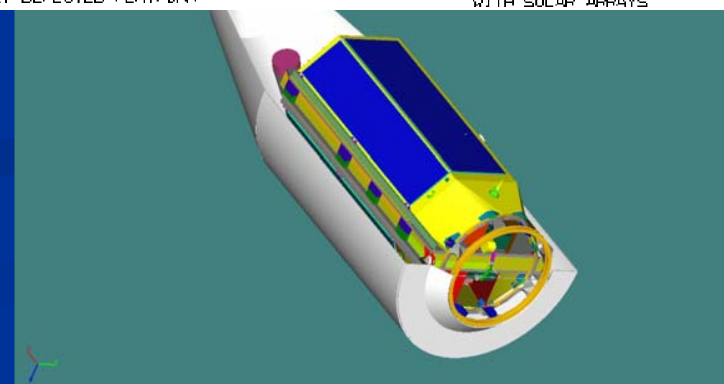
- **The data collection incidence angle range is from 15° to 60°**
- **Dual polarisation data acquisition is possible in all operational modes**
- **300 MHz experimental mode with 0.5 m slant range resolution**
- **Further experimental modes are feasible due to the Dual Receiving Antenna**

# TerraSAR-L

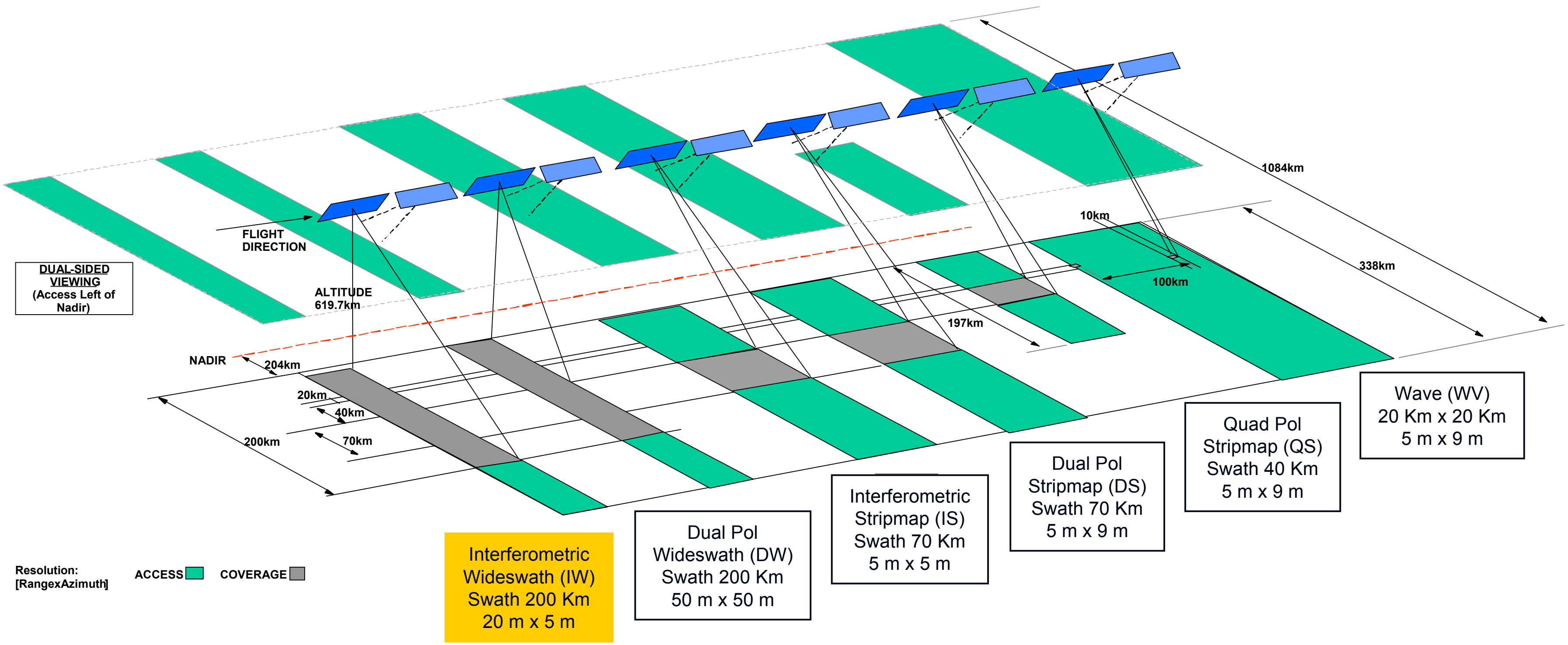
# The Spacecraft

- Snapdragon
- Mass: 2700 kg
  - 1800 kg p/l
  - 900 kg L-SAR
- Antenna: 32 $m^2$
- Power: 5 kW
  - 4.5 kW L-SAR
- On-board Memory: 622
- Data downlink: 300 MHz



# L-SAR Modes




- QS, DS, DW pol. + high radiometric performance
- IW, IS for interferometry – IW as main mode
- WV for wave spectra


Future SAR Systems
?

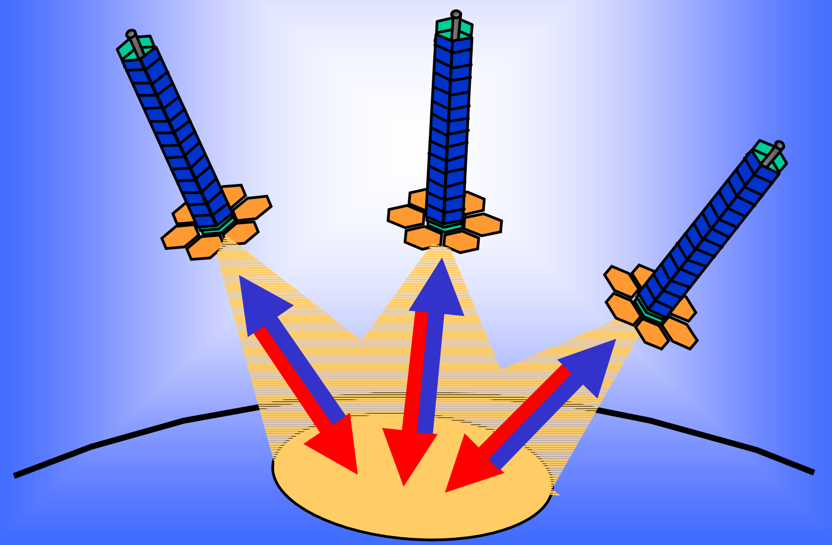
# *Future SAR Systems*

# Bistatic and Multistatic SAR Systems

- ***Bistatic* Systems**: spatial separation between transmitter and receiver
- ***Multistatic Systems:*** multiple transmitters/receivers

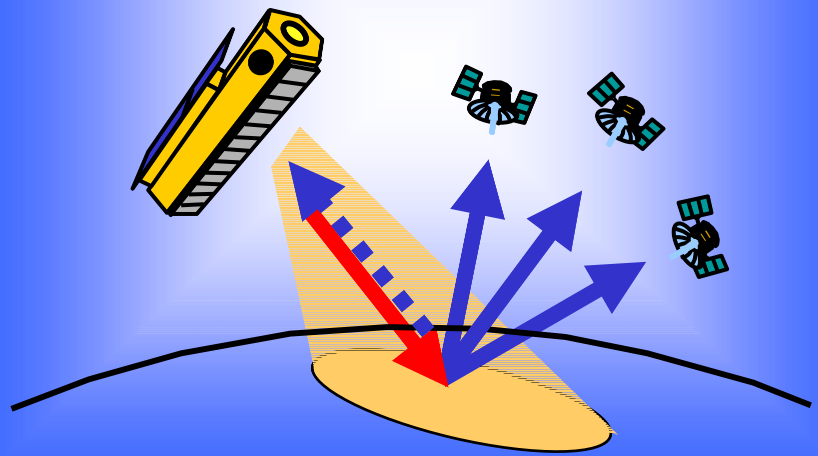
**Fully active system:**

- **TechSAT21, TanDEM-X, RADARSAT-2/3**

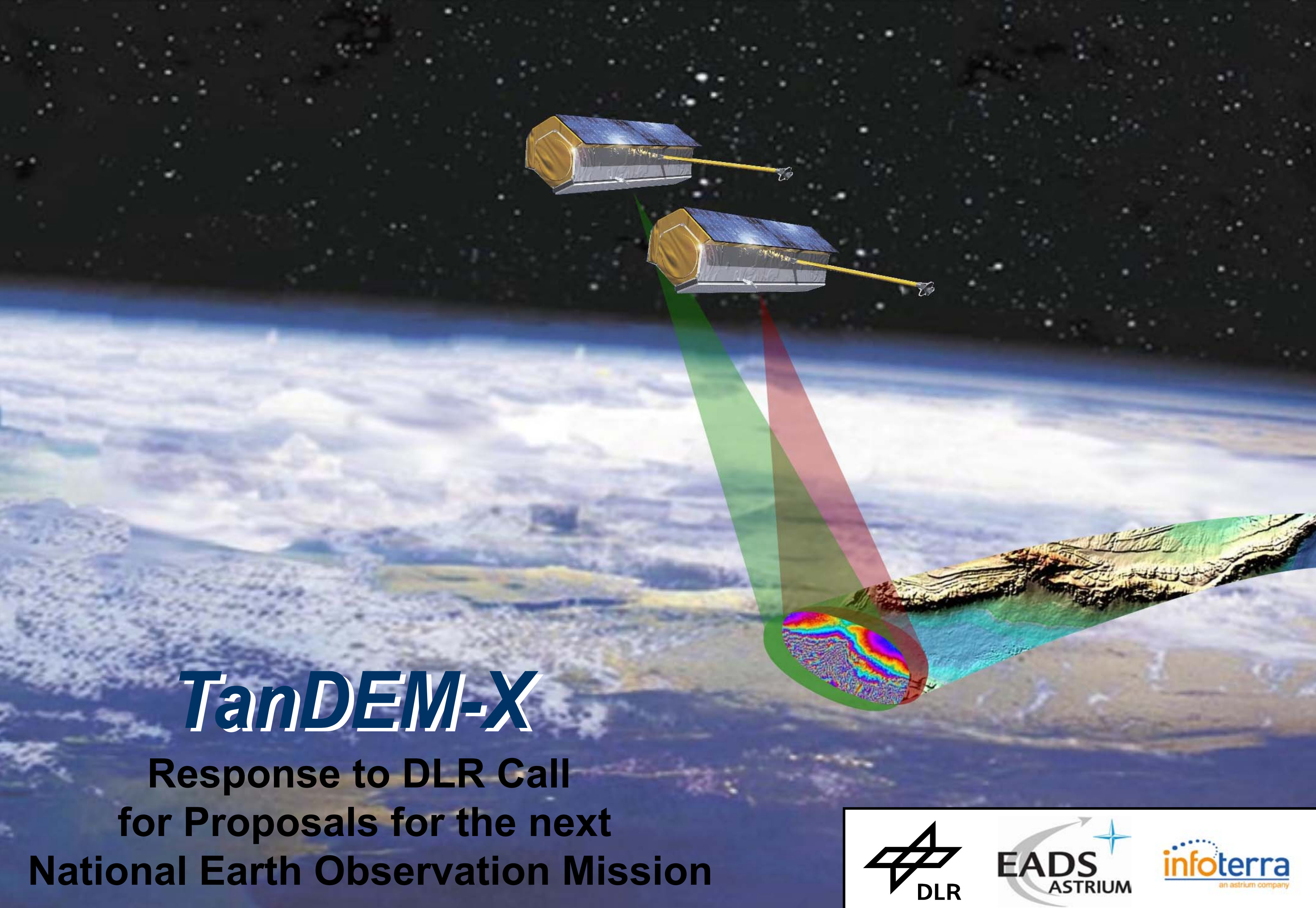


**Partially active system:**

- **ARGUS/FROMAGE, BISSAT, Cartwheel, Pendulum**



# TanDEM-X

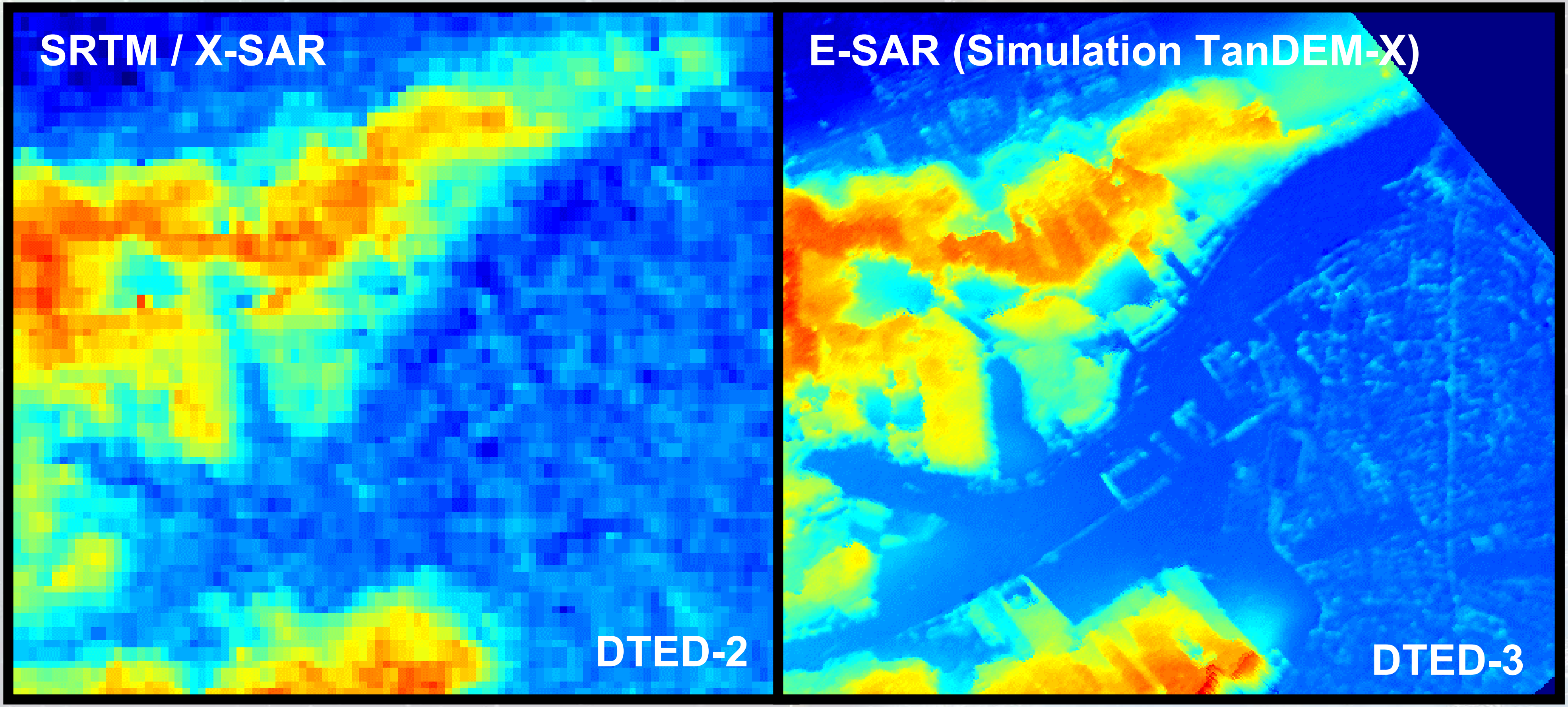


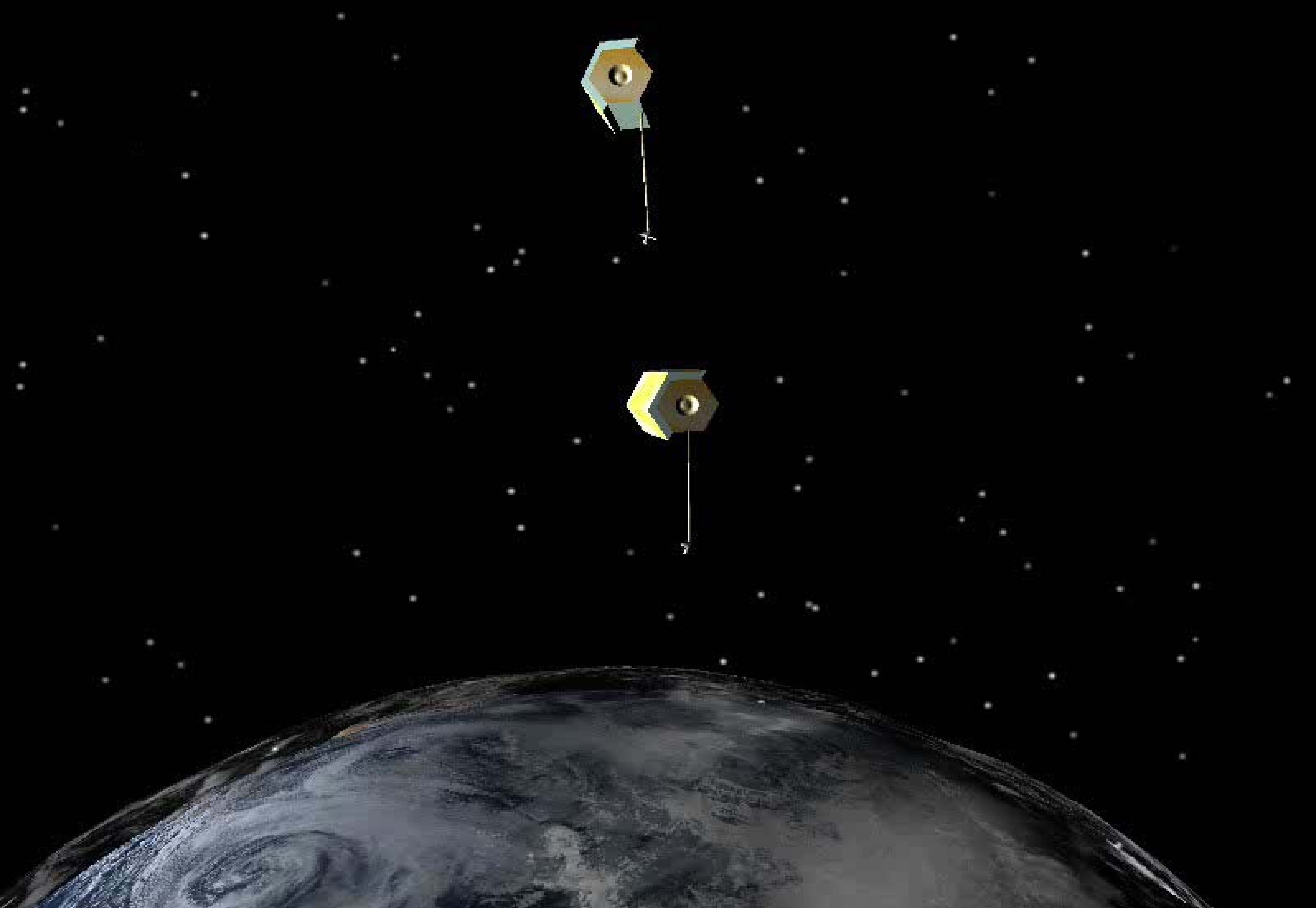
# TanDEM-X

**Response to DLR Call for Proposals for the next National Earth Observation Mission**

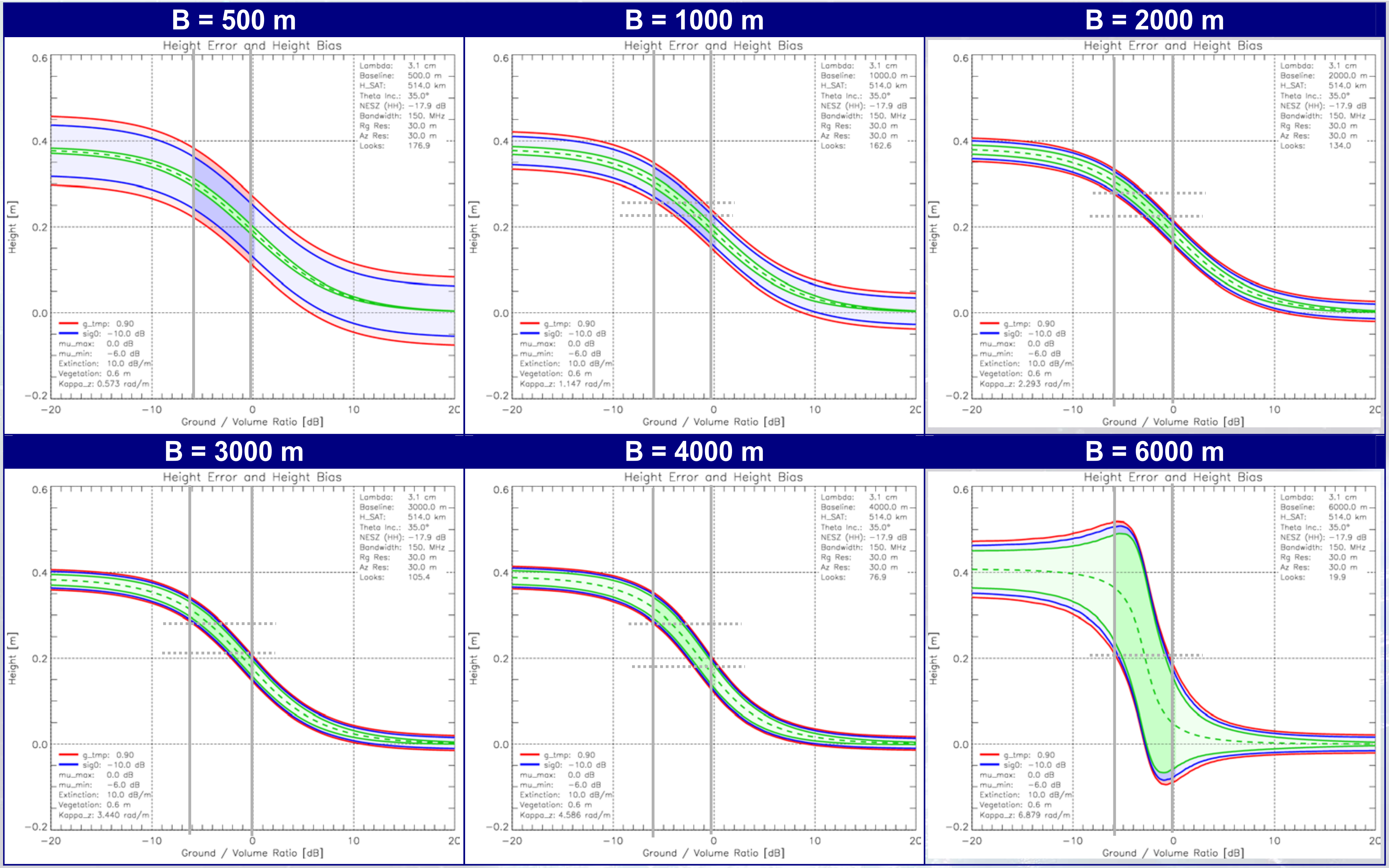
DLR EADS ASTRIUM infoterra an astrium company

# Interferometry with TanDEM-X





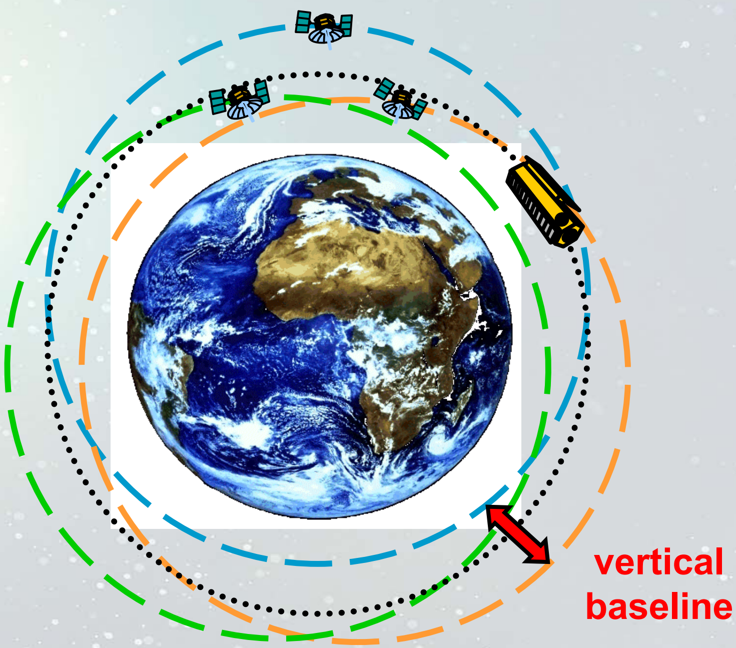
# Polarimetric Interferometry: Performance Estimation



# Micro-Satellite Concept

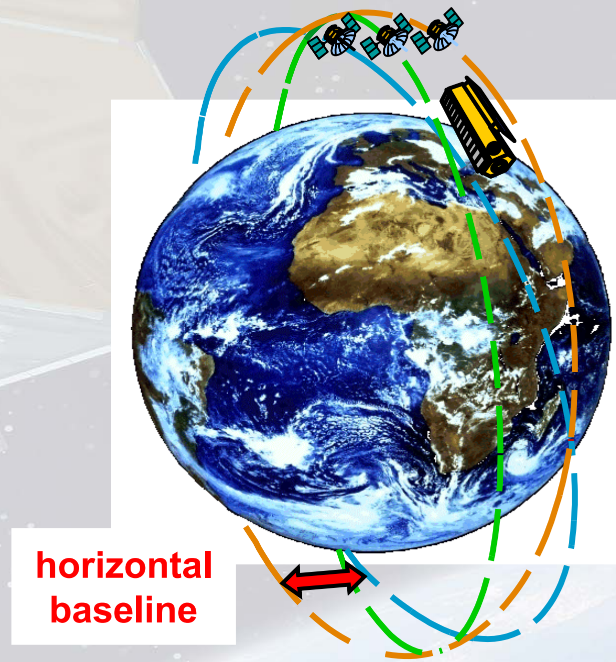
# Global High Resolution Interferometry

## Interferometric Cartwheel




Digital Elevation Model (DEM)
from SRTM Mission

## Cross-Track Pendulum




*<u>Single-Pass Cross-Track Interferometry with Multistatic Satellite Configuration:</u>*

- *no temporal decorrelation (as opposed to repeat-pass interferometry)*
- *no atmospheric distortions (as opposed to repeat-pass interferometry)*
- *large interferometric baselines (as opposed to e.g. SRTM)*

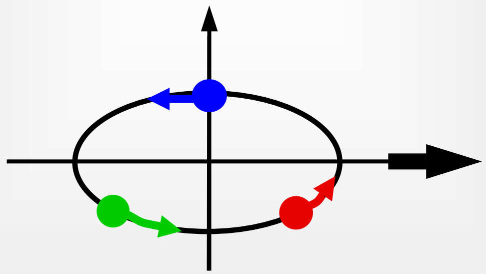
# Example: Interferometric Cartwheel

**Master Satellite:**

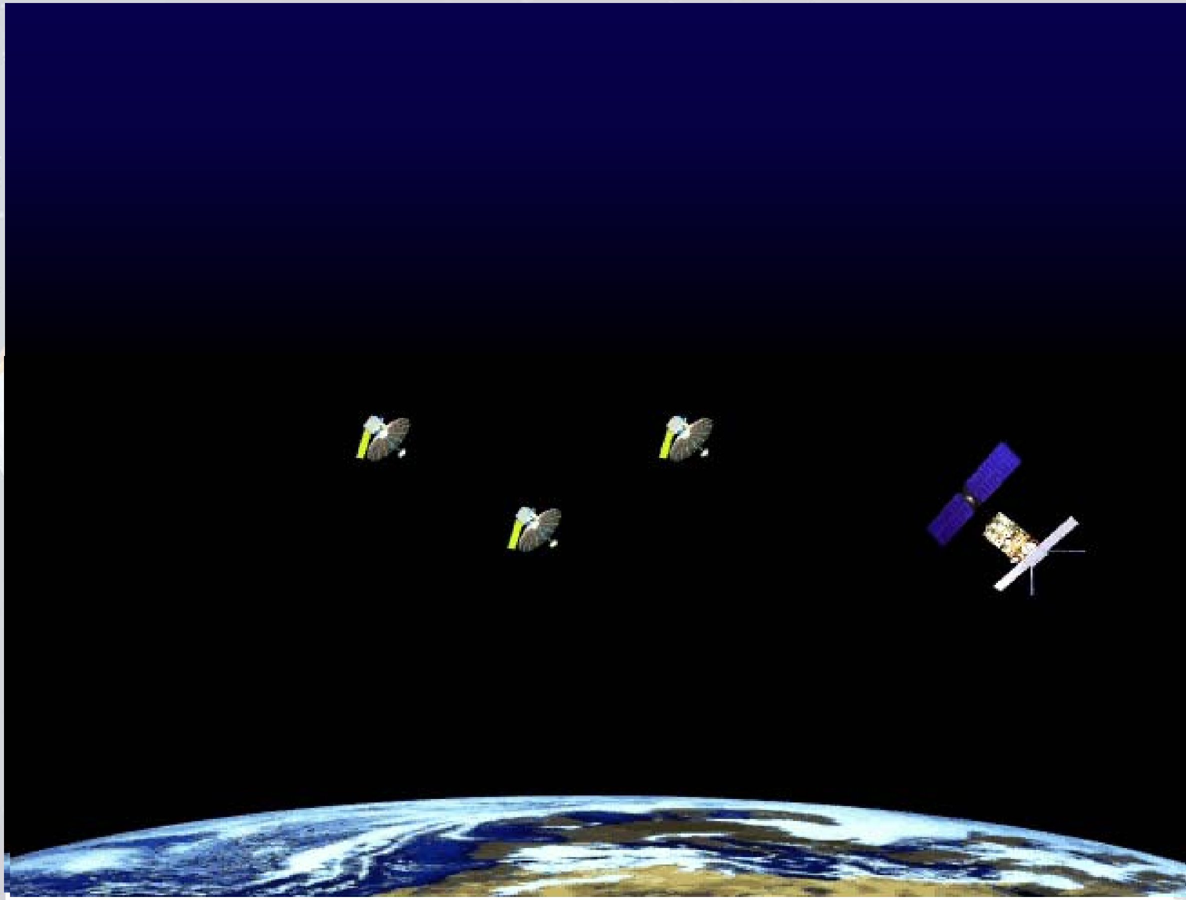
- e.g. circular orbit

**Receiver Satellites:**

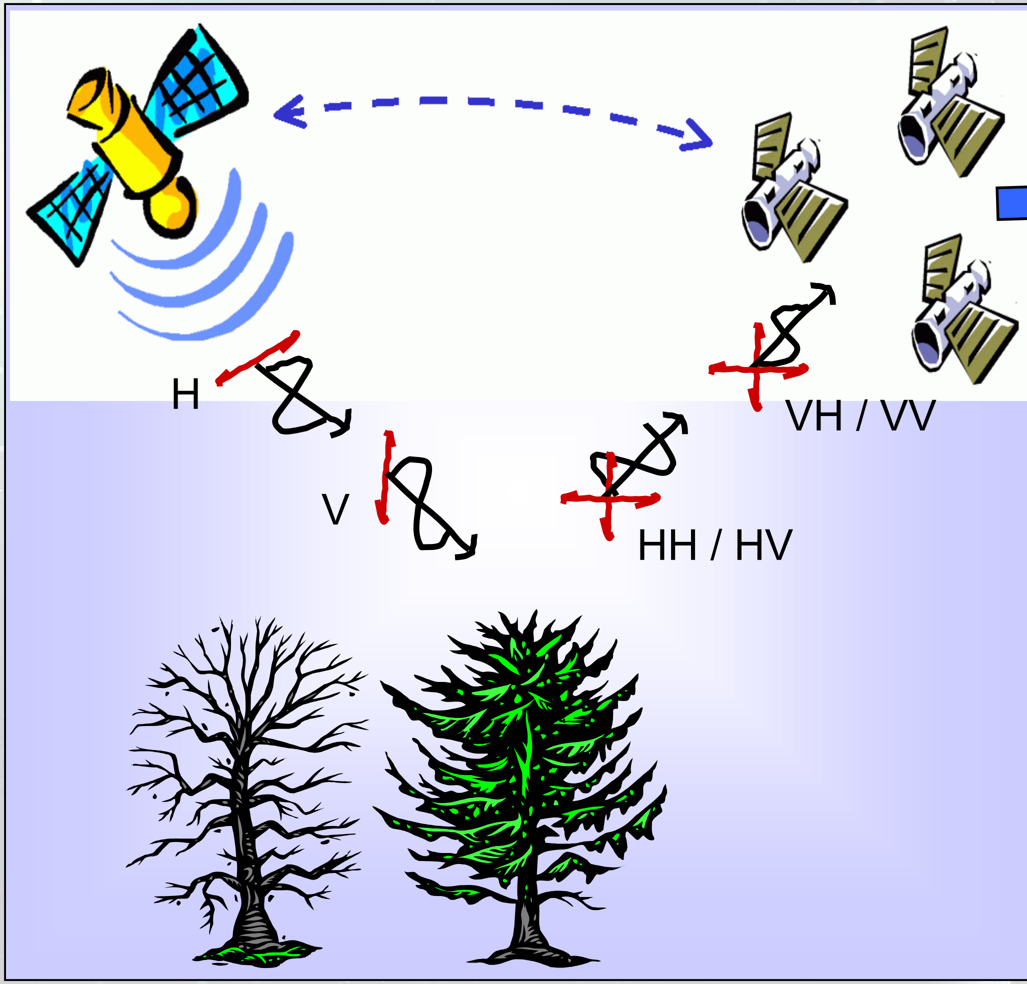
- elliptical orbits with equal eccentricities
- arguments of apogee differ by 120º for a Cartwheel with 3 satellites
- very stable maximum vertical baseline for all orbital positions
- relative movement of receivers may be approximated by CW-ellipse:



- coupling of along-track and across-track baselines



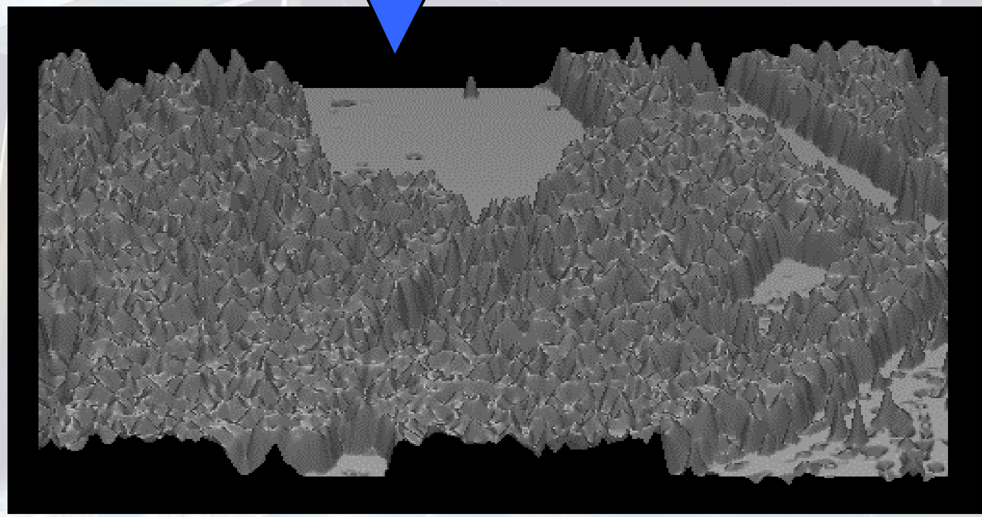
# Polarimetric Interferometry with Passive Micro-Satellite Configuration




**Inversion of Coherent Scattering Model**

**(e.g. Random Volume + Ground)**

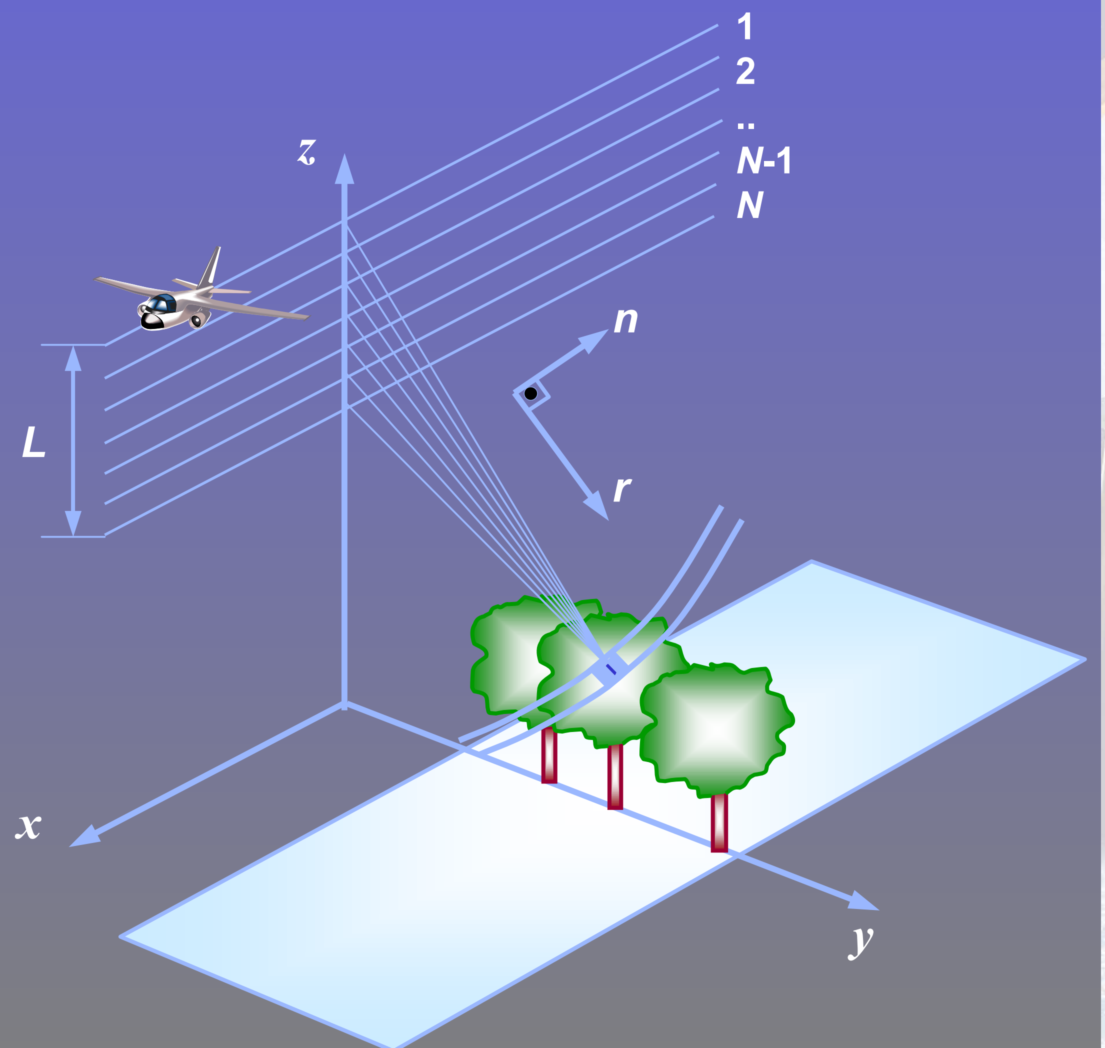
$h_V, \sigma, \phi_0, m_{1-3}$



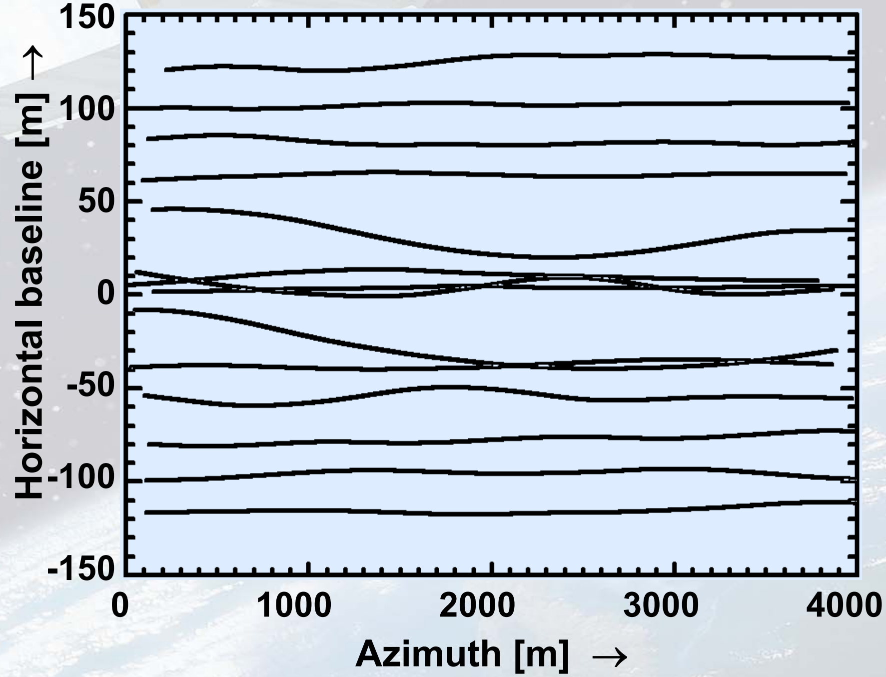
***Estimated forest height***

# *Multi-Baseline Approach*

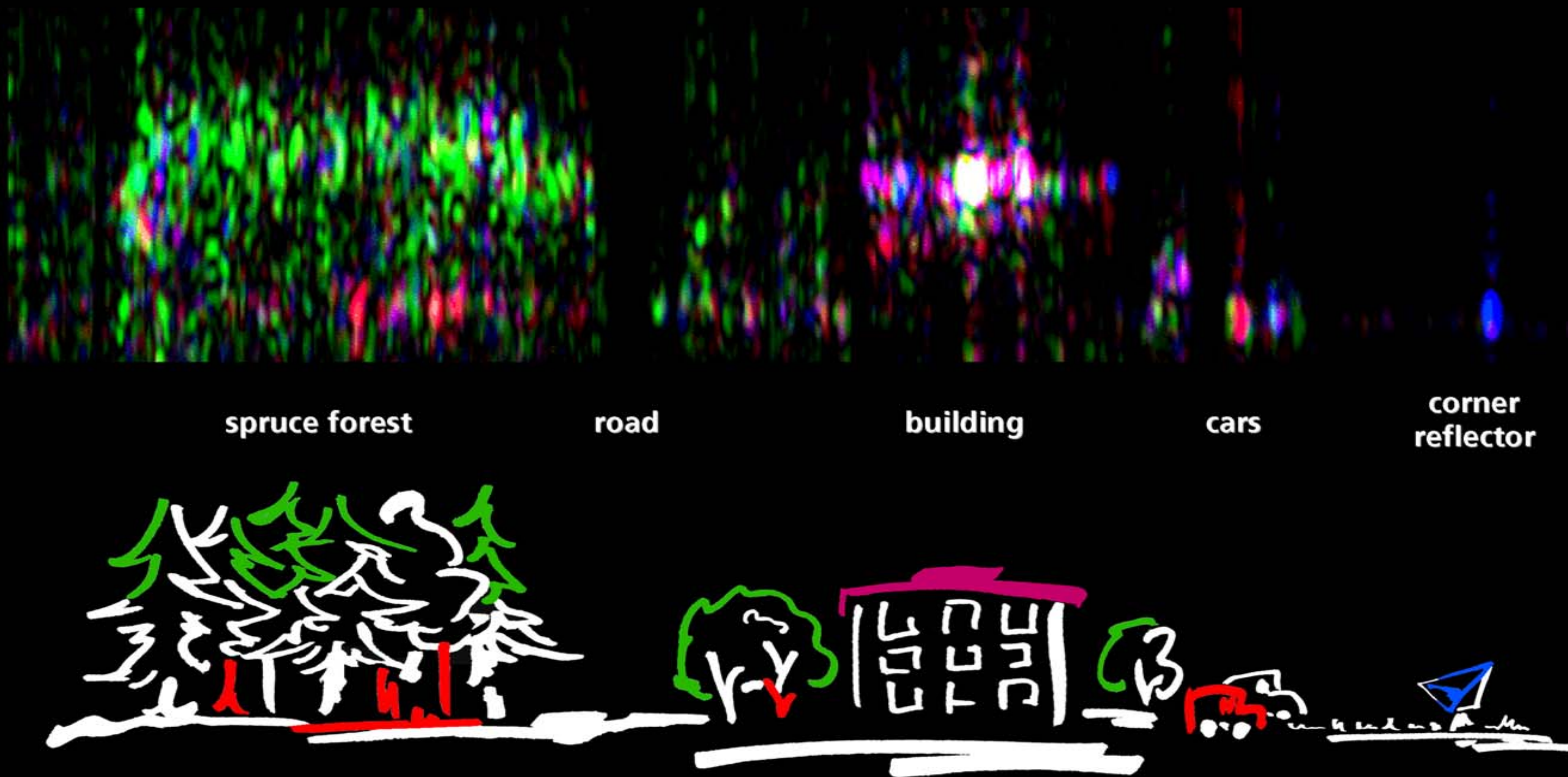
# Basic Geometry for SAR Tomography




Measured Baseline with airborne experiment



# First Demonstration of Airborne SAR-Tomography




**Airborne Polarimetric SAR Tomography**

**Upper image: Polarimetric color composite (L-band) of a tomographic slice in the height/azimuth-direction**

**HH+VV, HH-VV, 2*HV**

**Lower image: Schematic view of the imaged area**

* A. Reigber und A. Moreira: "First Demonstration of Airborne SAR Tomography using Multibaseline L-Band Data". IEEE TGRS, Vol. 38 (5), Sept. 2000

# High-Resolution Wide-Swath

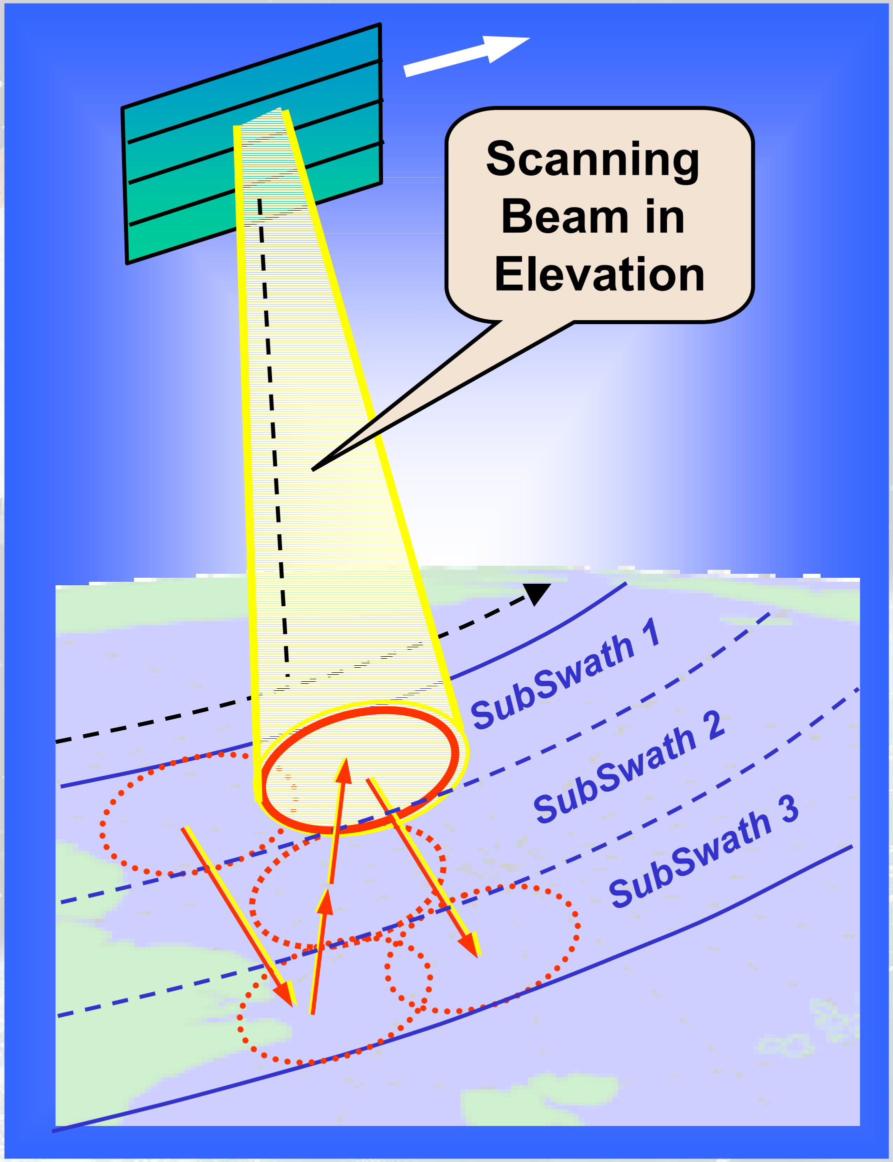
# ScanSAR Imaging Mode

- ***Standard approach for wide swath imaging***

- ***Basic idea:***
  - *Divide wide swath in multiple subswaths*
  - *Scan subswaths in sequential order by appropriate beam steering in elevation (e.g. by using T/R modules)*

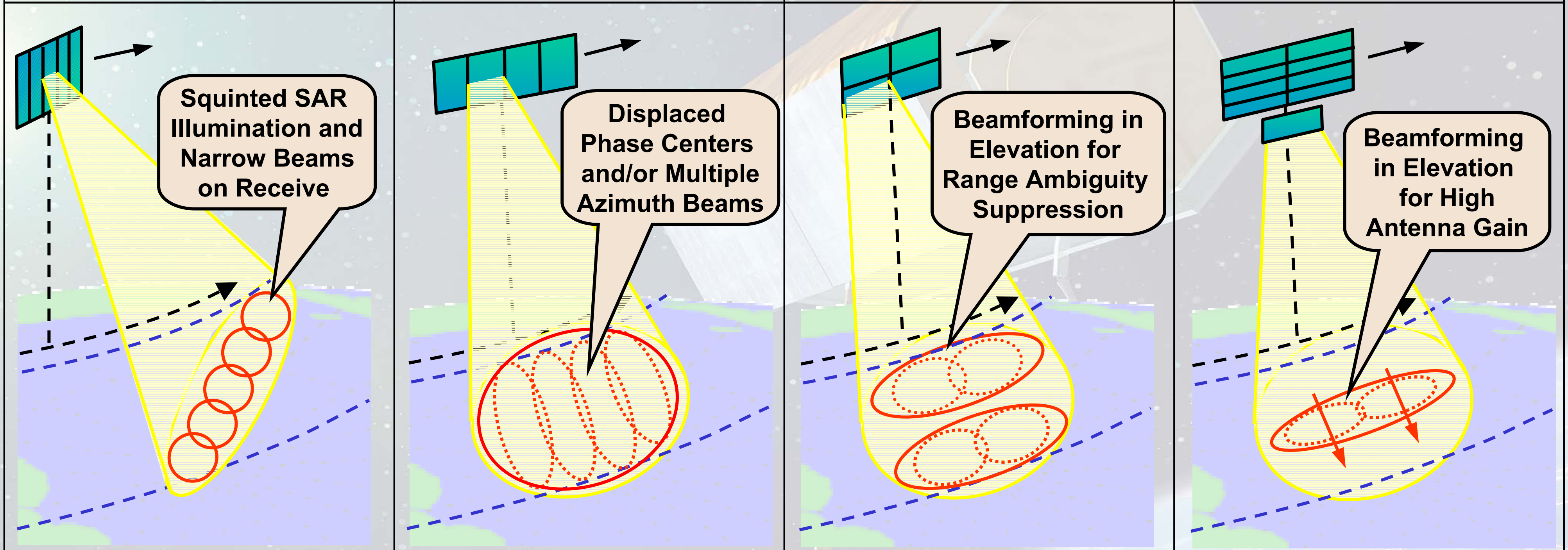
- ***Shares full aperture synthesis time between multiple swaths:***

  $\Rightarrow$ ***Reduced azimuth resolution***



# Solutions to Wide Swath SAR Imaging

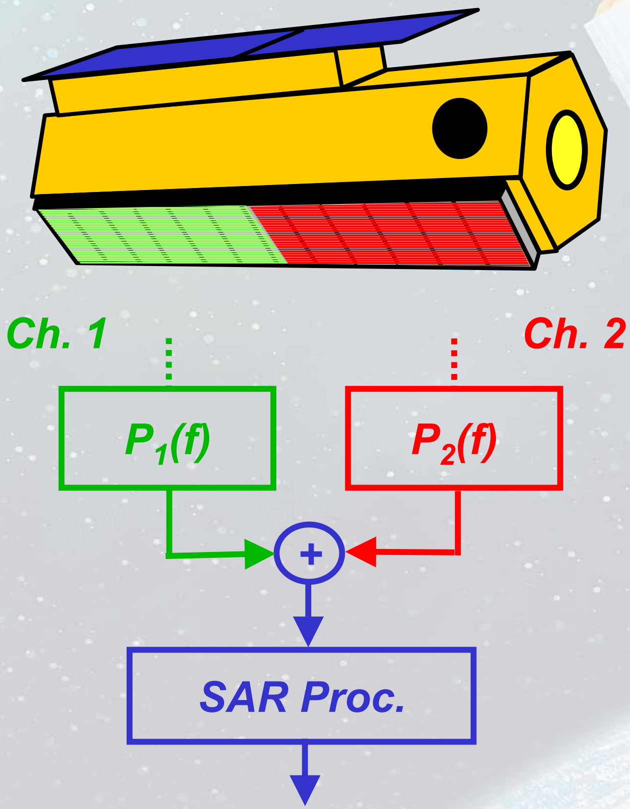
| MultiBeam | DPC | Quad Array | HRWS |
|---|---|---|---|
| Claassen & Eckerman (1983)<br>Jean & Rouse (1983) | Currie & Brown (1992) | Callaghan & Longstaff (1999) | Süss & Wiesbeck (2001)<br>Younis & Wiesbeck (2002) |




| MultiBeam | DPC | Quad Array | HRWS |
|---|---|---|---|
| • almost constant incident angle across whole swath<br>• wide swath imaging requires high squint | • good azimuth resolution<br>• wide image swath<br>• long receiving antenna<br>• stringent PRF requirement | • good azimuth resolution<br>• compact antenna<br>• range gap in the middle of the swath | • good azimuth resolution<br>• high receive gain by real-time beamforming<br>• long receiving antenna |

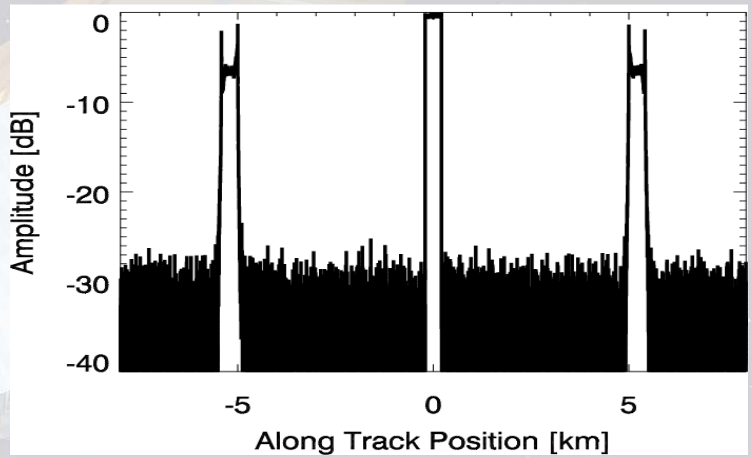
# High Resolution with Dual Receive Antenna

| | |
|---|---|
| Wavelength | 3.1 cm |
| Antenna Length (Tx) | 2.4 m (4.8 m / 2) |
| Sub-Aperture Length (Rx) | 2.4 m (4.8 m / 2) |
| PRF | 3600 Hz |
| Velocity | 7600 m/s |
| Channel SNR | 20 dB |

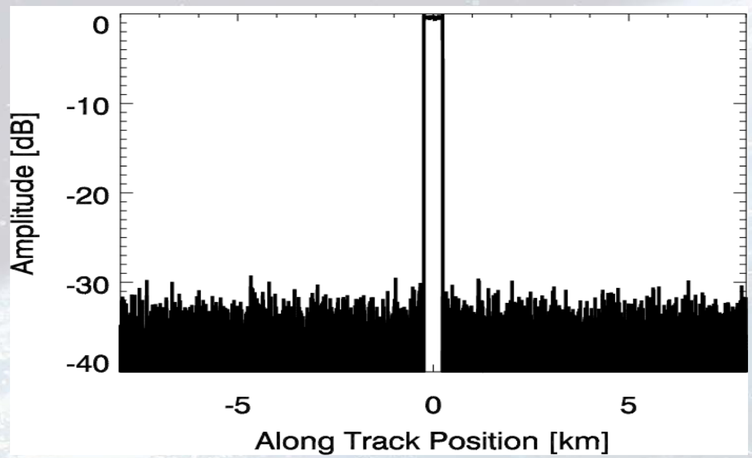



## Response to Extended Scatterer

*without reconstruction*




*with reconstruction*

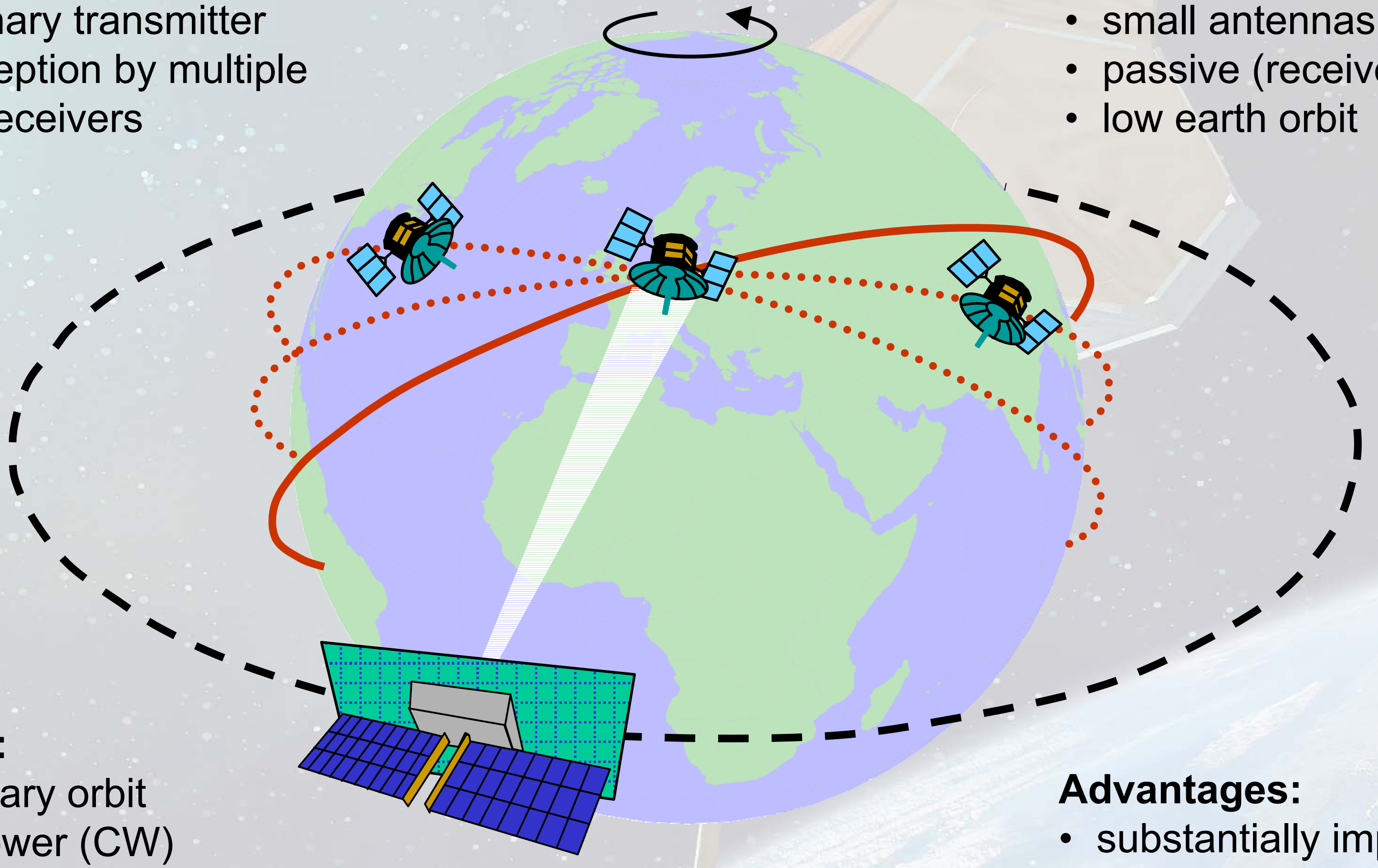


# Satellite Constellations

# Geostationary Illuminator / LEO Receivers

**Basic Idea:**
- constant illumination by geostationary transmitter
- signal reception by multiple low-cost receivers

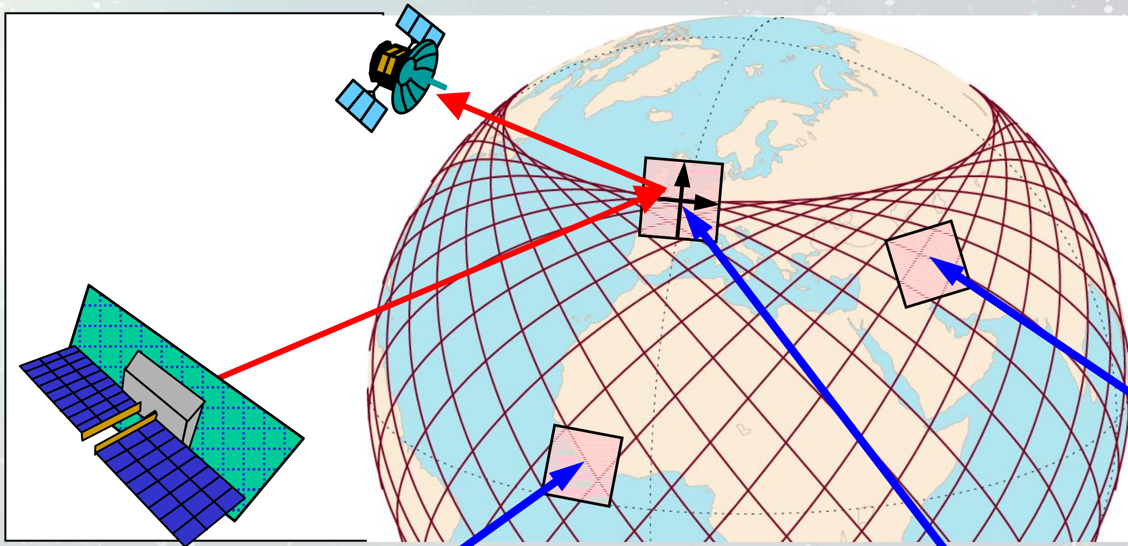
**Receivers:**
- low-cost micro-satellites
- small antennas
- passive (receive only)
- low earth orbit



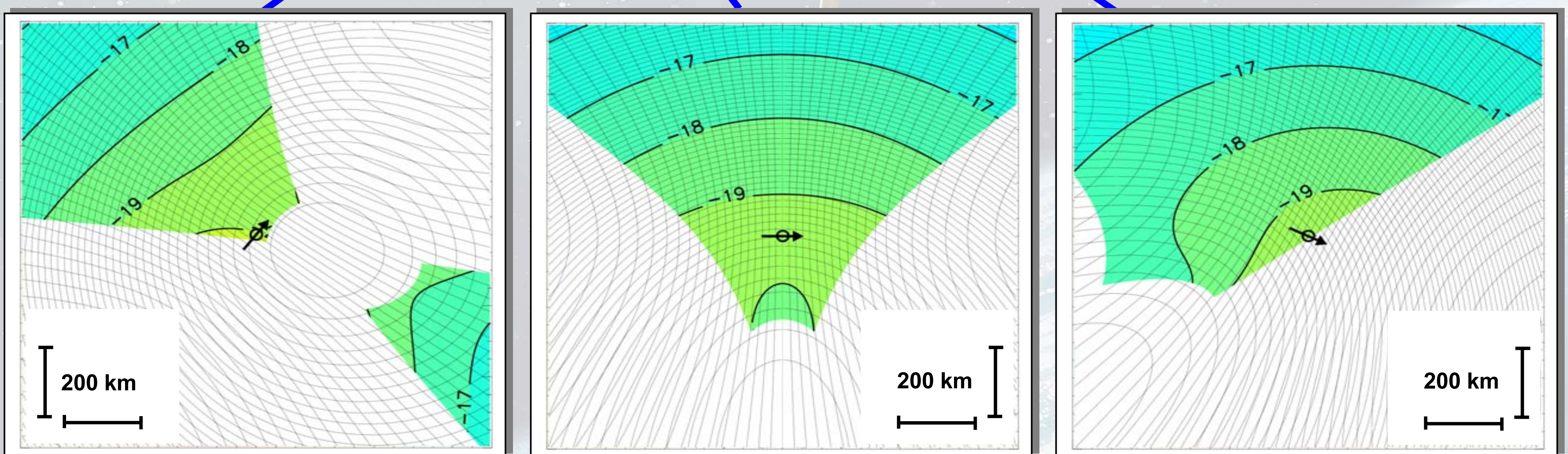
**Illuminator:**
- geostationary orbit
- high Tx power (CW)
- large antenna area
- optional: steerable antenna

**Advantages:**
- substantially improved revisit times without cost explosion
- multiple missions may share one illuminator

# Geostationary Illuminator: Sensitivity

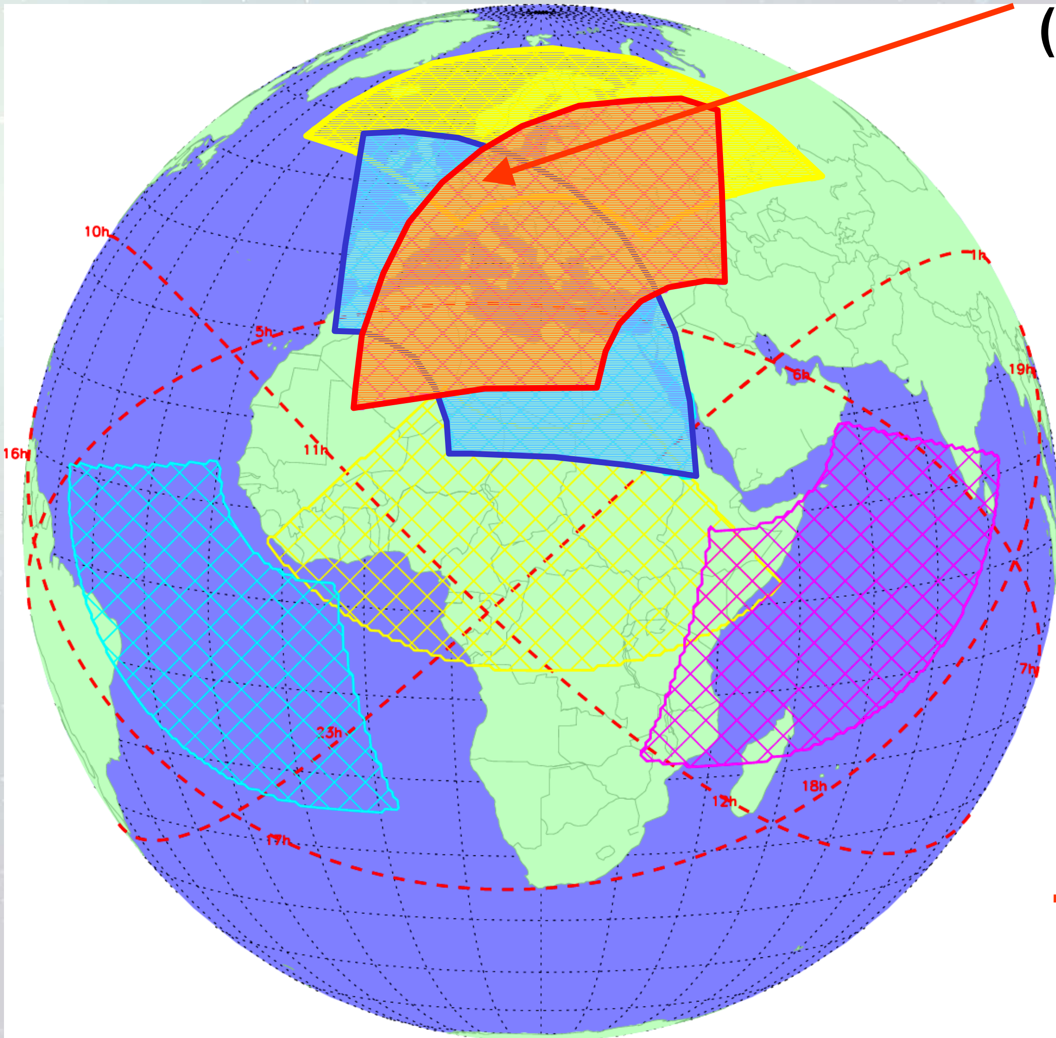


| | |
|---|---|
| Wavelength | 3.1 cm |
| Max. Bandwidth | 300 MHz |
| Average Transmit Power | 1000 W |
| Antenna Size Tx | 100 $m^2$ |
| Antenna Size Rx | 6 $m^2$ |
| Noise Figure + Losses | 5 dB |
| Receiver Altitude | 400 km |
| Ground Range Resolution | 3 m |
| Max. Res. Cell Diameter | 6 m |



# An Alternative: MEO Orbits

**3 revisits / day (for 1 satellite)**




- Example: Orbit with an inclination of 35° and 5 cycles/day (altitude: ~ 8000km)
- Integration time for 3m azimuth resolution: ~ 10 sec
- NESZ: ~ -30dB (X-Band, $P_{Tx}$= 1 kW, $A_{Tx}$=100 m$^2$)
- Huge simultaneous access area
- Long observation times enable change detection in one pass

**MEO SAR Constellations are an interesting alternative to the geostationary illuminator concept**

# New Ways Forward

- **Multi-static SAR**
  - enables smaller and cheaper satellites
  - provides more information and increased sensitivity
  - benefits from advanced technologies

- **Digital beam forming**
  - makes full use of information at antenna array
  - improves performance

- **Satellite constellations**
  - may share common illuminator
  - symbiotic use of platforms (e.g. with Nav./Com.)
  - allow for decreased revisit times