

# Future SAR Technologies and Mission Concepts

Alberto Moreira

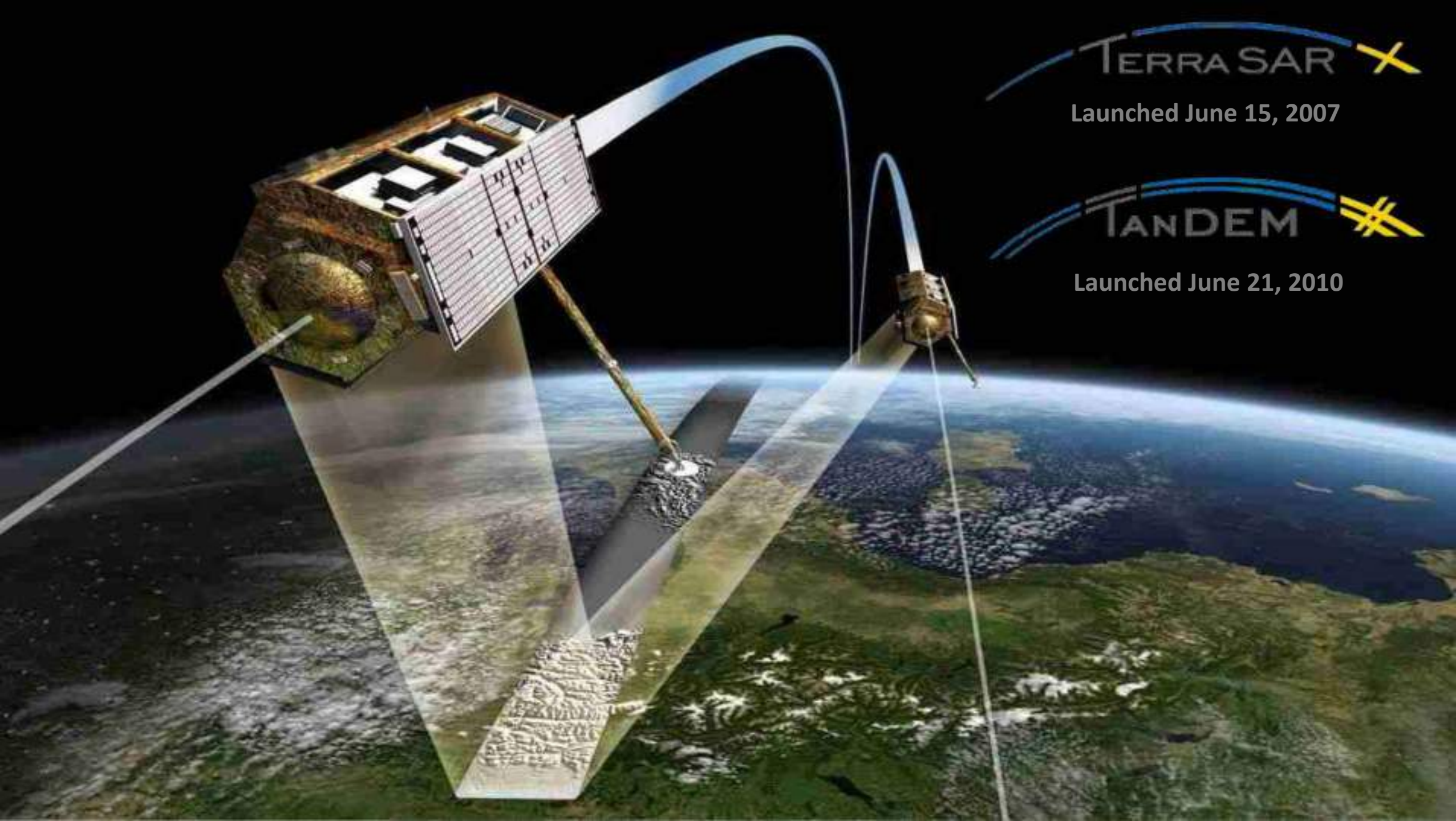
**German Aerospace Center**

Microwaves and Radar Institute

Oberpfaffenhofen



Knowledge for Tomorrow



TERRASAR X

Launched June 15, 2007

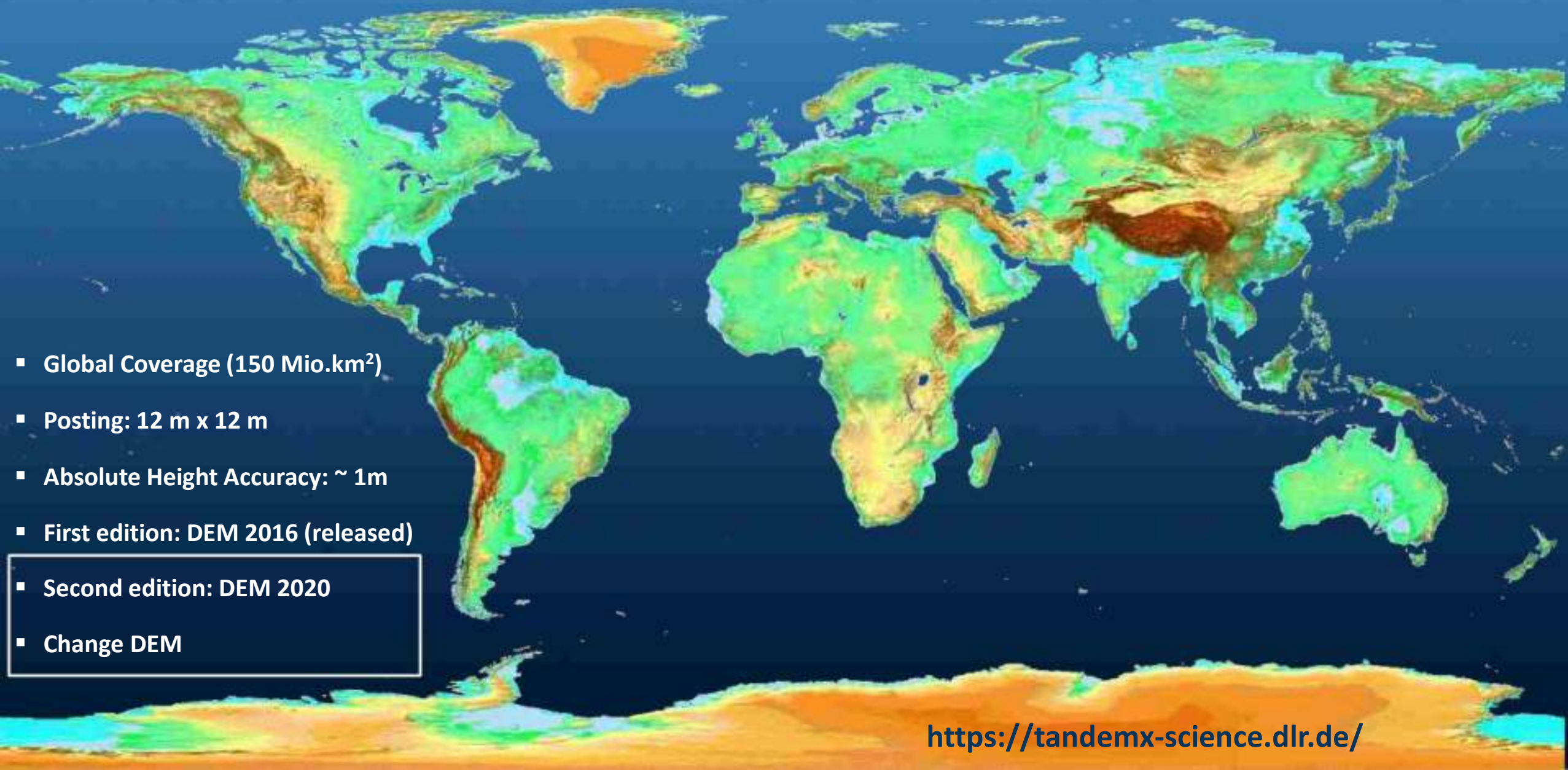
TANDEM X

Launched June 21, 2010



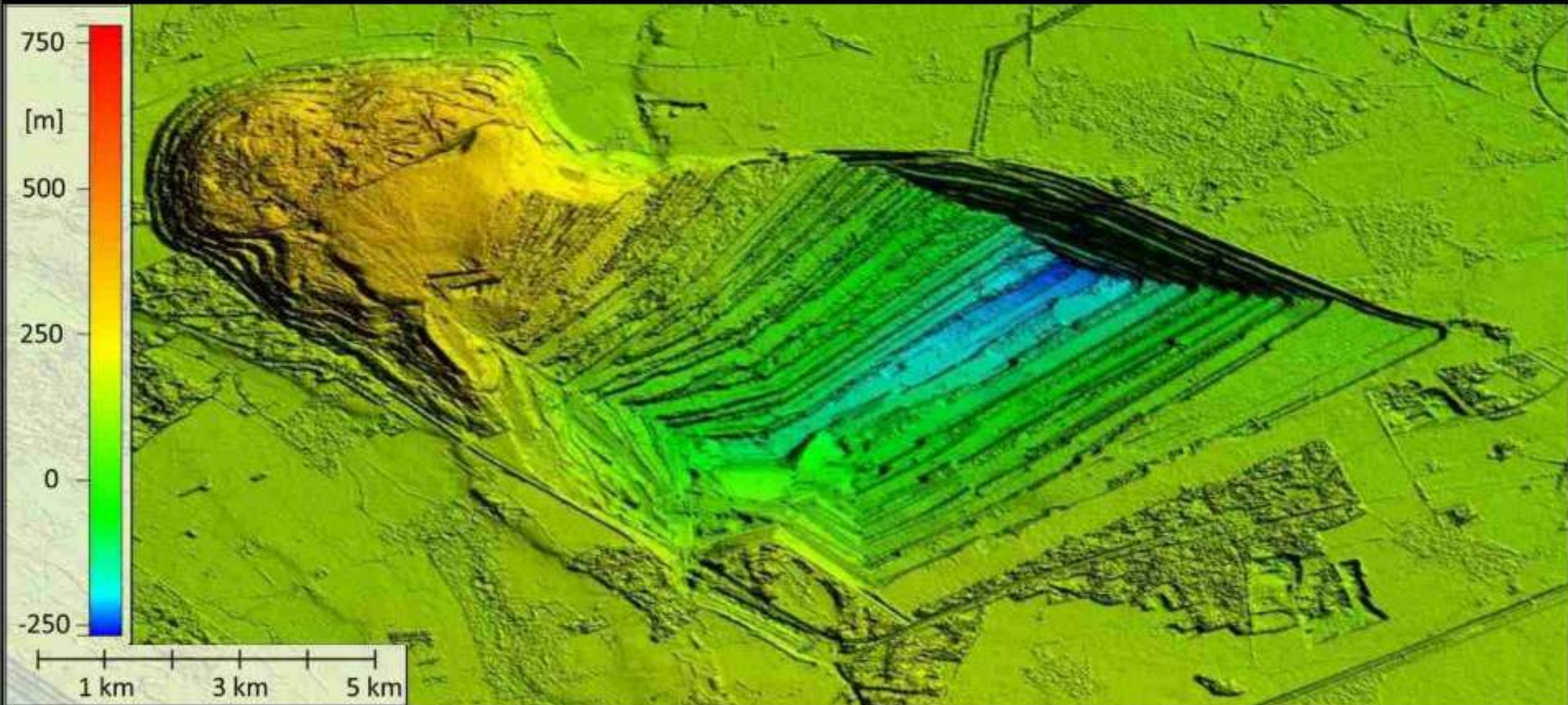
The image shows a satellite constellation in orbit over Earth. Two satellites are visible, connected by thin lines. The word "TANDEM" is written in large, grey, sans-serif capital letters across the center. Above the text, there are two thick blue curved lines and a yellow graphic element on the right consisting of several intersecting lines. The background is a view of Earth from space, showing the blue ocean and white clouds.

# TANDEM

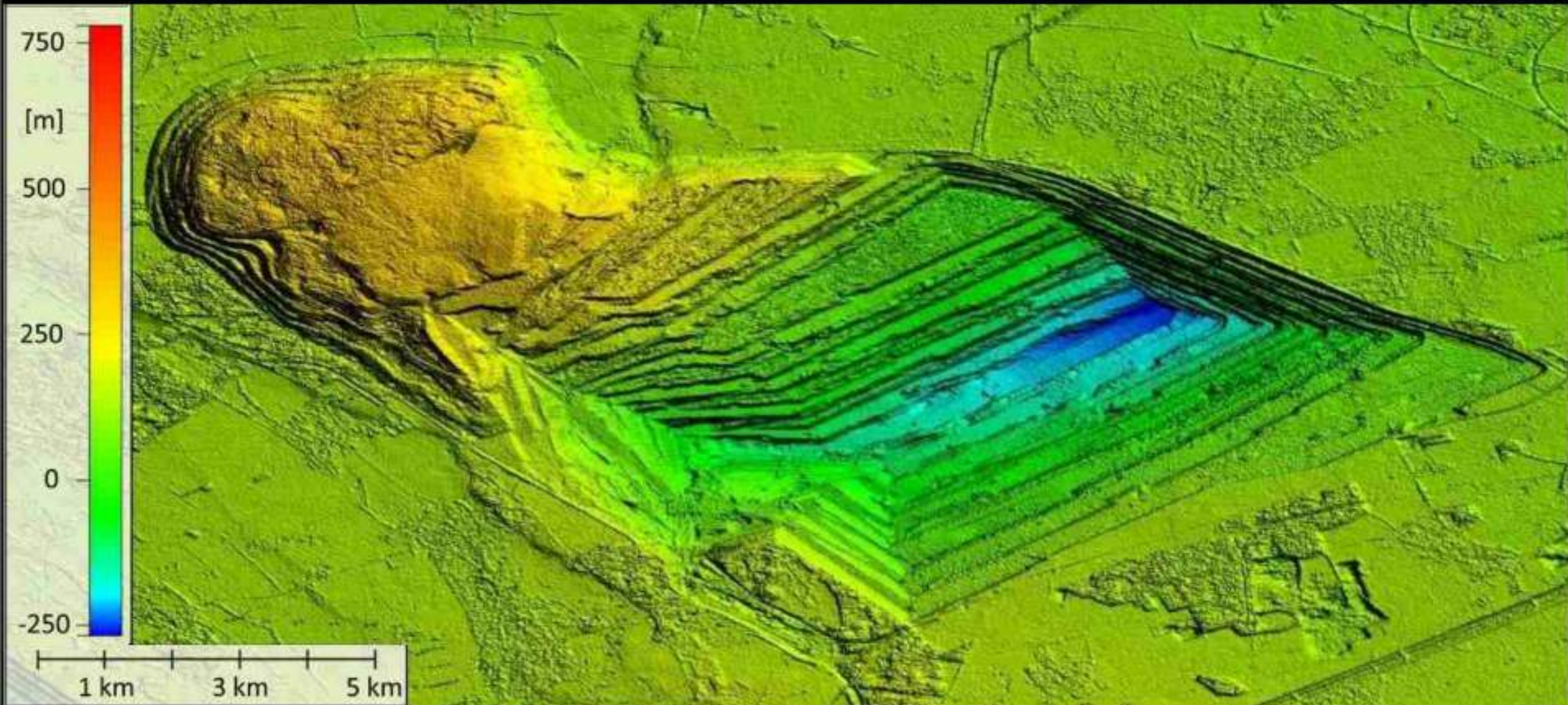


- Global Coverage (150 Mio.km<sup>2</sup>)
- Posting: 12 m x 12 m
- Absolute Height Accuracy: ~ 1m
- First edition: DEM 2016 (released)
- Second edition: DEM 2020
- Change DEM

# TanDEM-X DEM 2016



# TanDEM-X DEM 2020





10.5 km

Image © 2011 CNES / Airbus  
Image Landsat / Copernicus

Google Earth



# Lake Taupo, New Zealand





# Lake Taupo, New Zealand, Change DEM



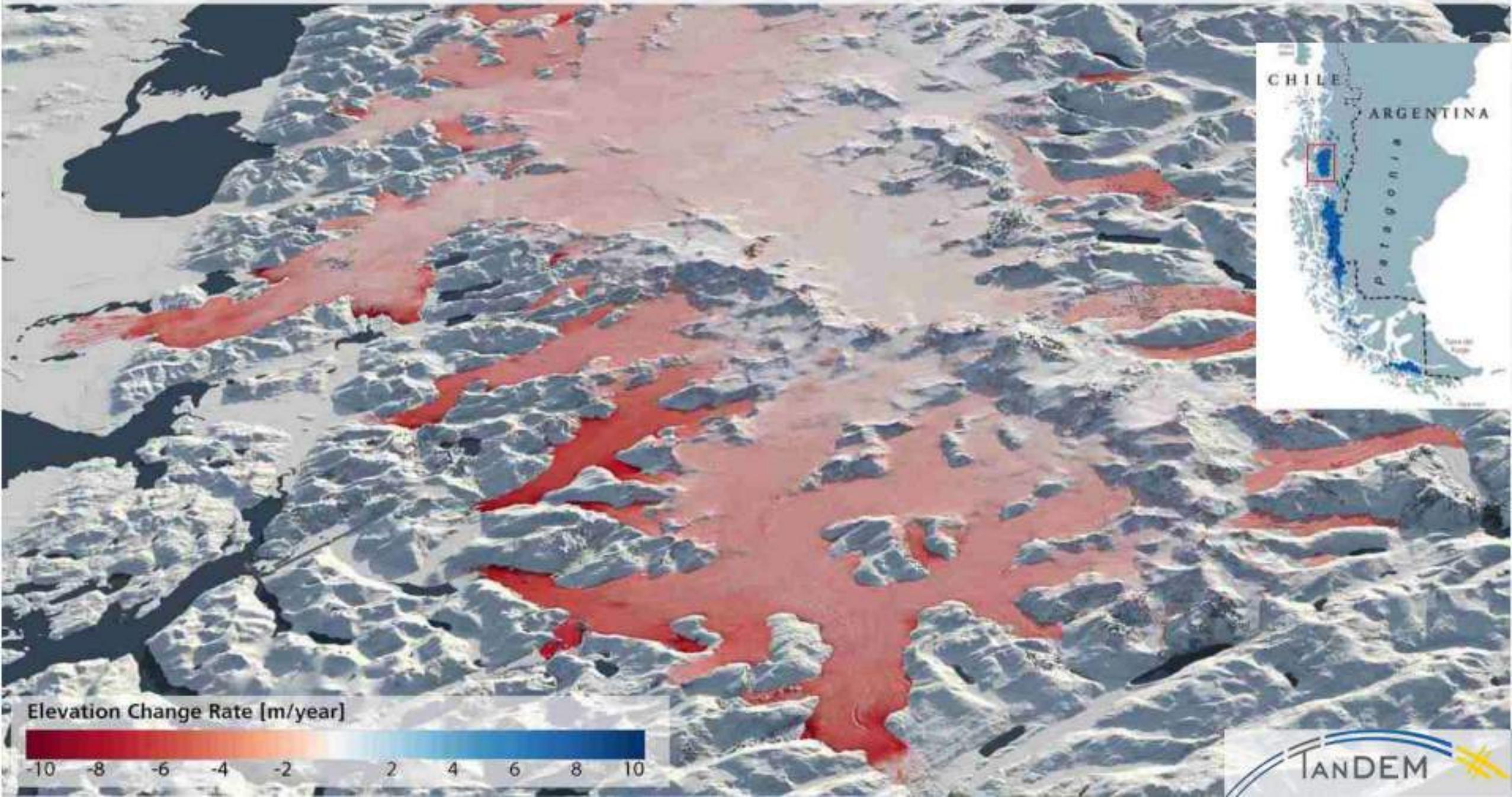





**Rain Forest, Rondonia, Brazil (Change DEM)**

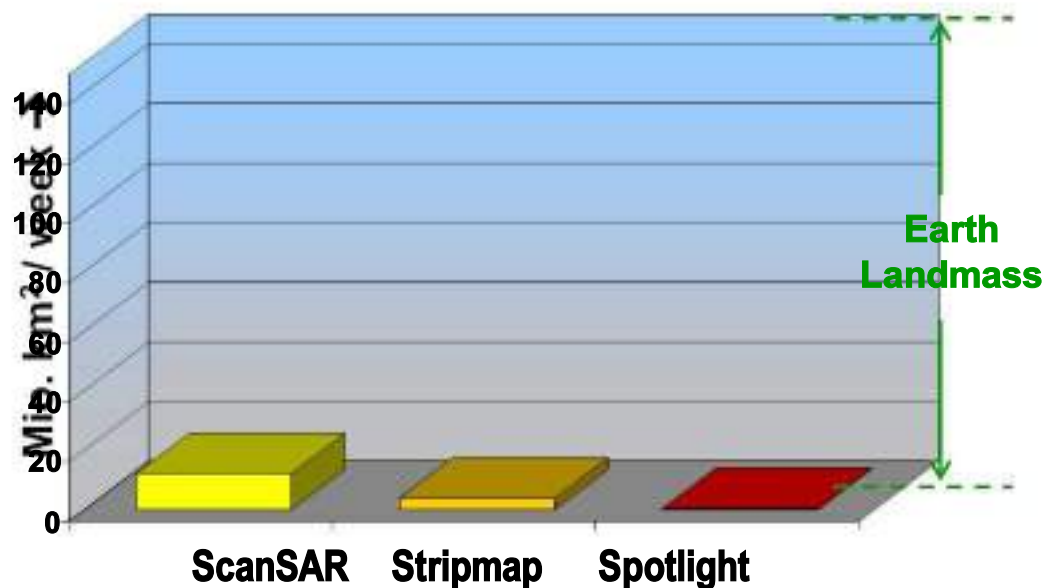


# Melting of the North-Patagonian Ice Field



# Mapping Capacity of TerraSAR-X / TanDEM-X

	Imaging Mode			
	Wide ScanSAR	ScanSAR	Stripmap	Spotlight
Resolution	40 m	16 m	3 m	1 m
Swath Width	270 km	100 km	30 km	10 km
Duty Cycle	3-5 minutes / orbit			

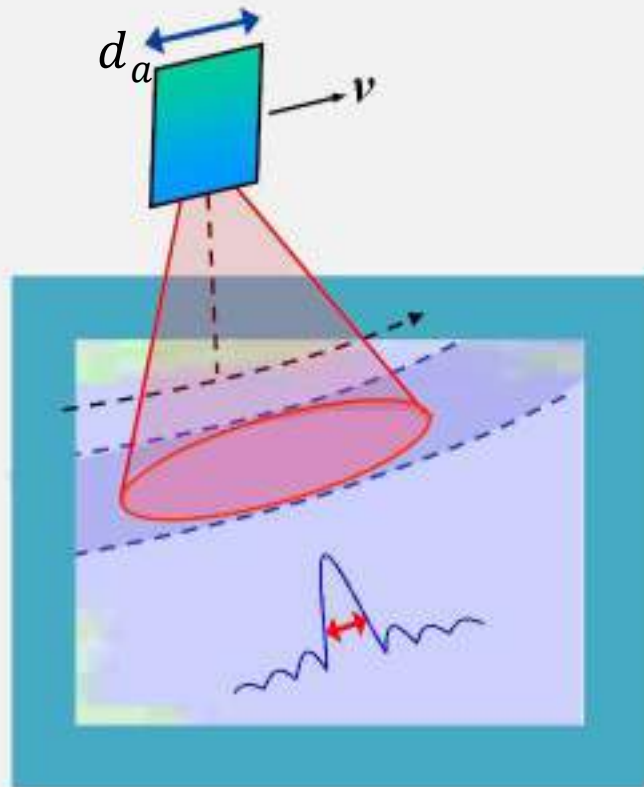


1  
Day



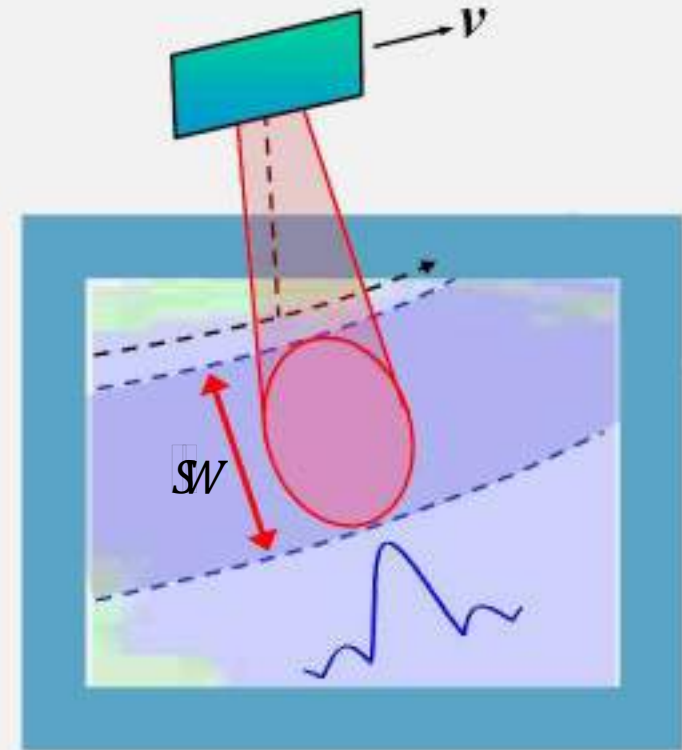
# Limitations of conventional SAR

Case 1: High azimuth resolution



$$PRF > \frac{2 \cdot v}{d_a}$$

Case 2: Large swath width



$$PRF < \frac{c}{2 \cdot SW \cdot \sin \theta_i}$$

PRF = Pulse Repetition Rate

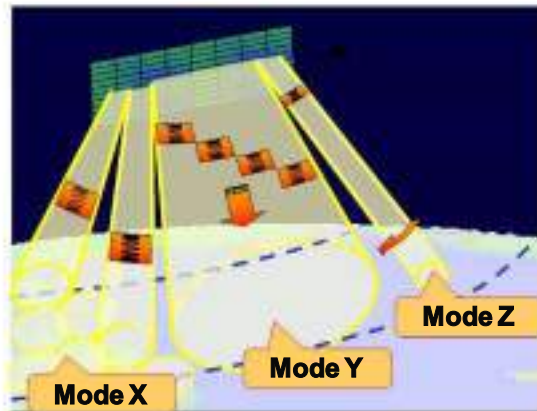


# SAR Systems: State of the Art and Future Requirements



State of the Art (Sentinel-1)	Imaging Mode (single/dual pol.)		
	EW	IW	SM
Resolution	40 m	20 m	5 m
Swath Width	400 km	250 km	80 km
Orbit Duty Cycle	25 minutes per orbit		

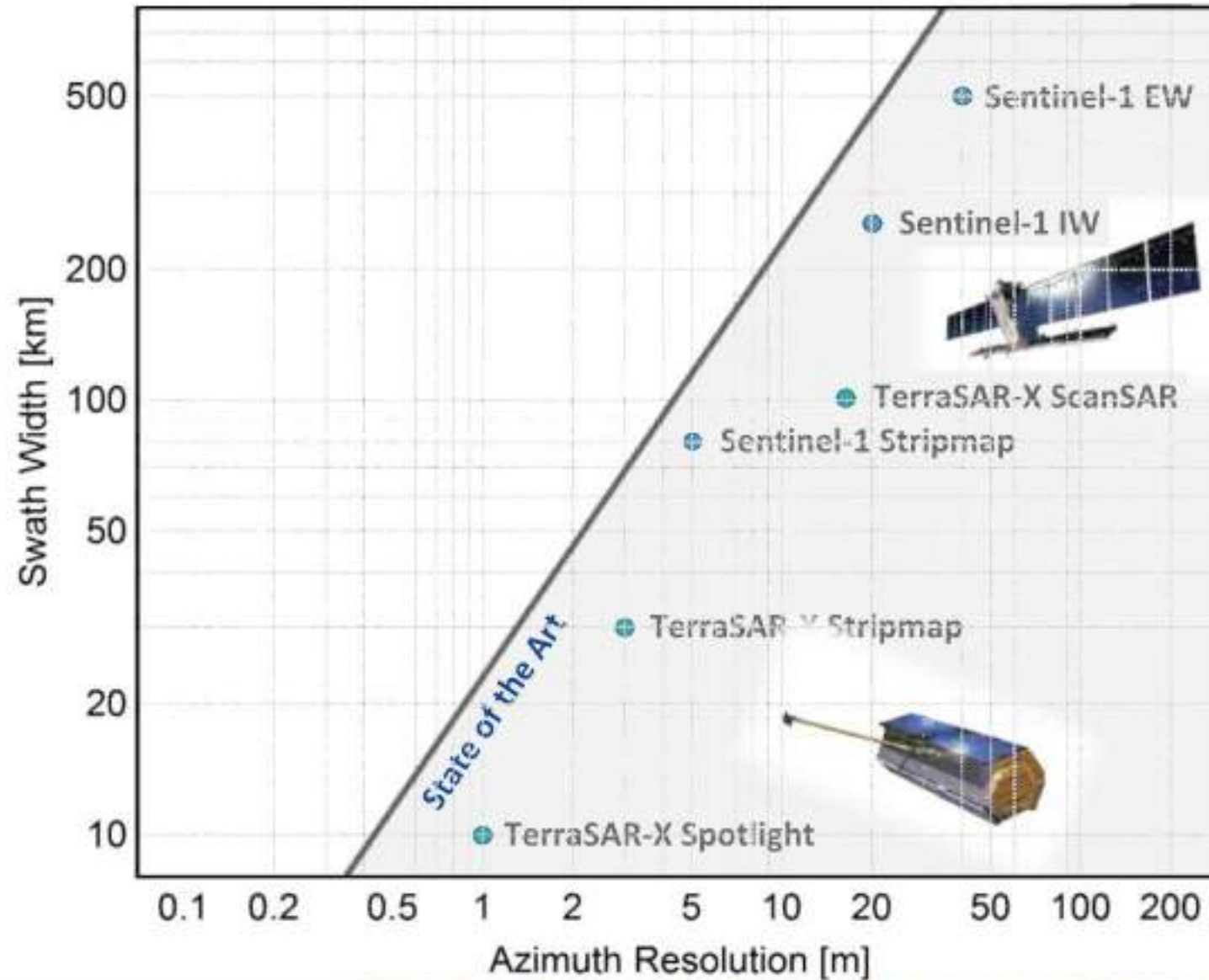
Resolution ↔ Swath Width ↔ Repeat Cycle



Future Requirements	Imaging Mode (quad pol.)		
	Mode X	Mode Y	Mode Z
Resolution	5 m	2 m	1 m
Swath Width	500 km	200 km	100 km
Orbit Duty Cycle	> 50 minutes per orbit		



# A Constraint of the Spaceborne SAR Systems



# The Future of Synthetic Aperture Radar...

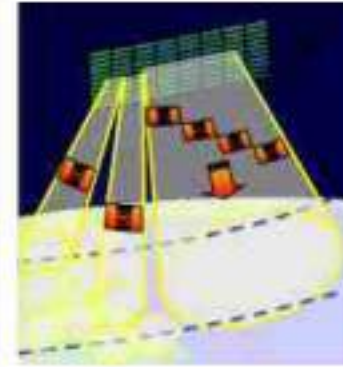
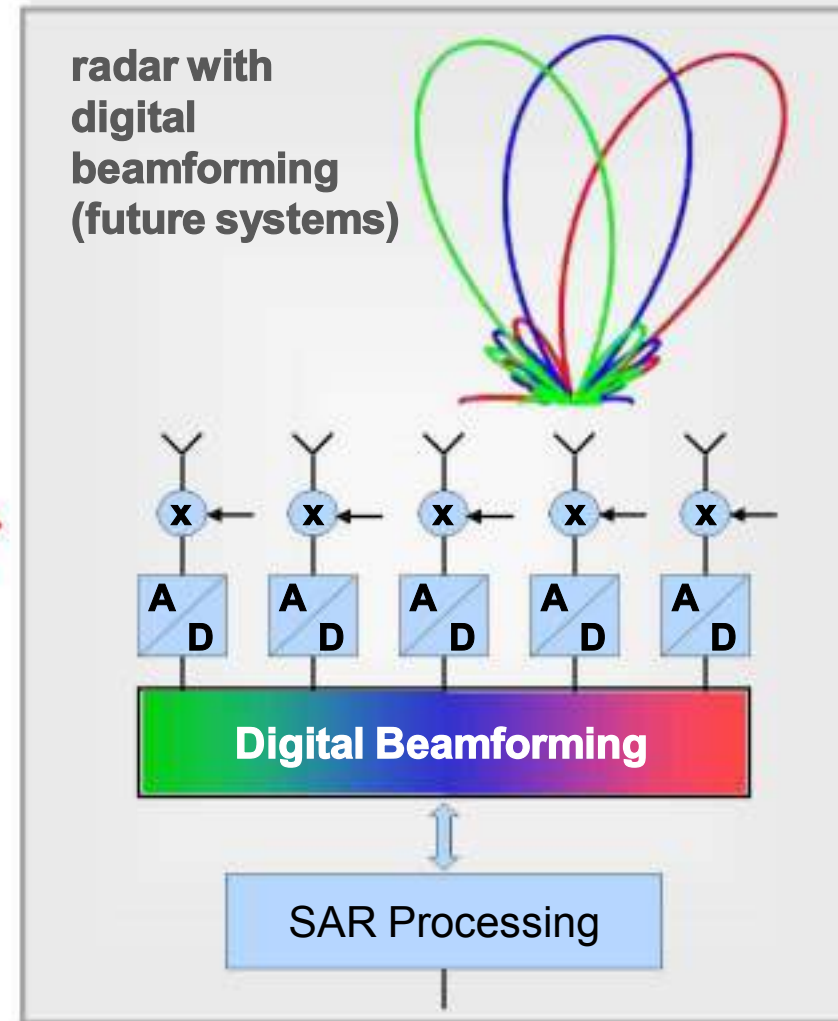
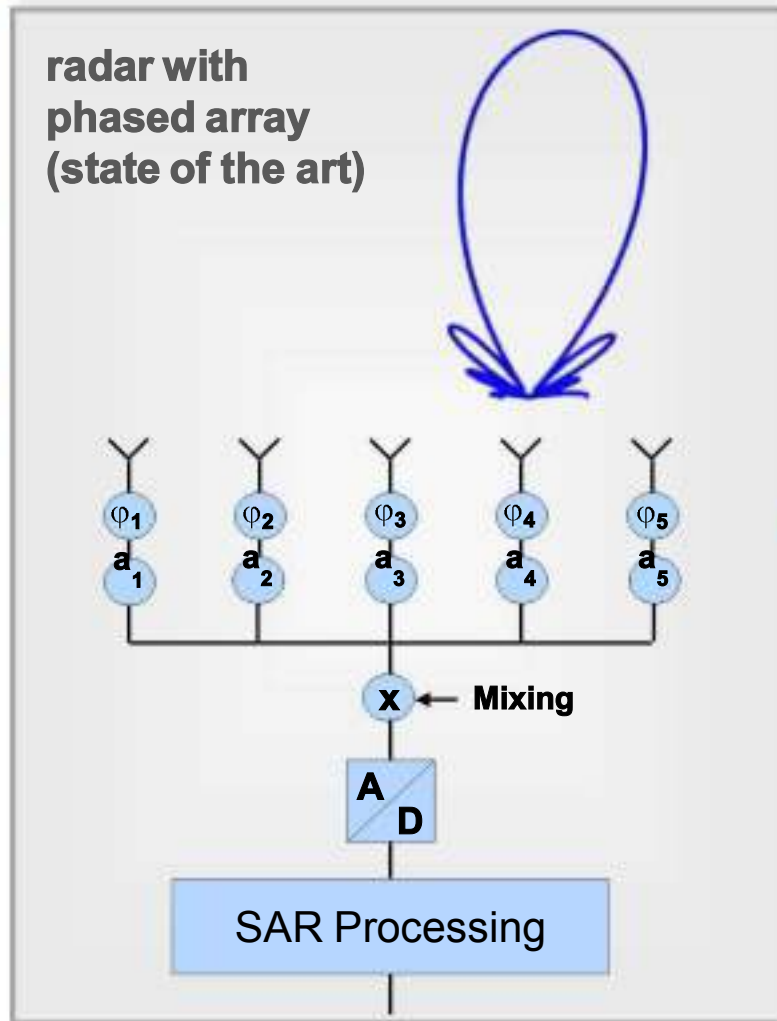


**...Digital Beamforming: A Paradigm Shift!**

# Digital Beamforming / Multichannel SAR



Sentinel-1,  
TerraSAR-X,  
ALOS-2,  
Radarsat-2,  
RCM, etc.

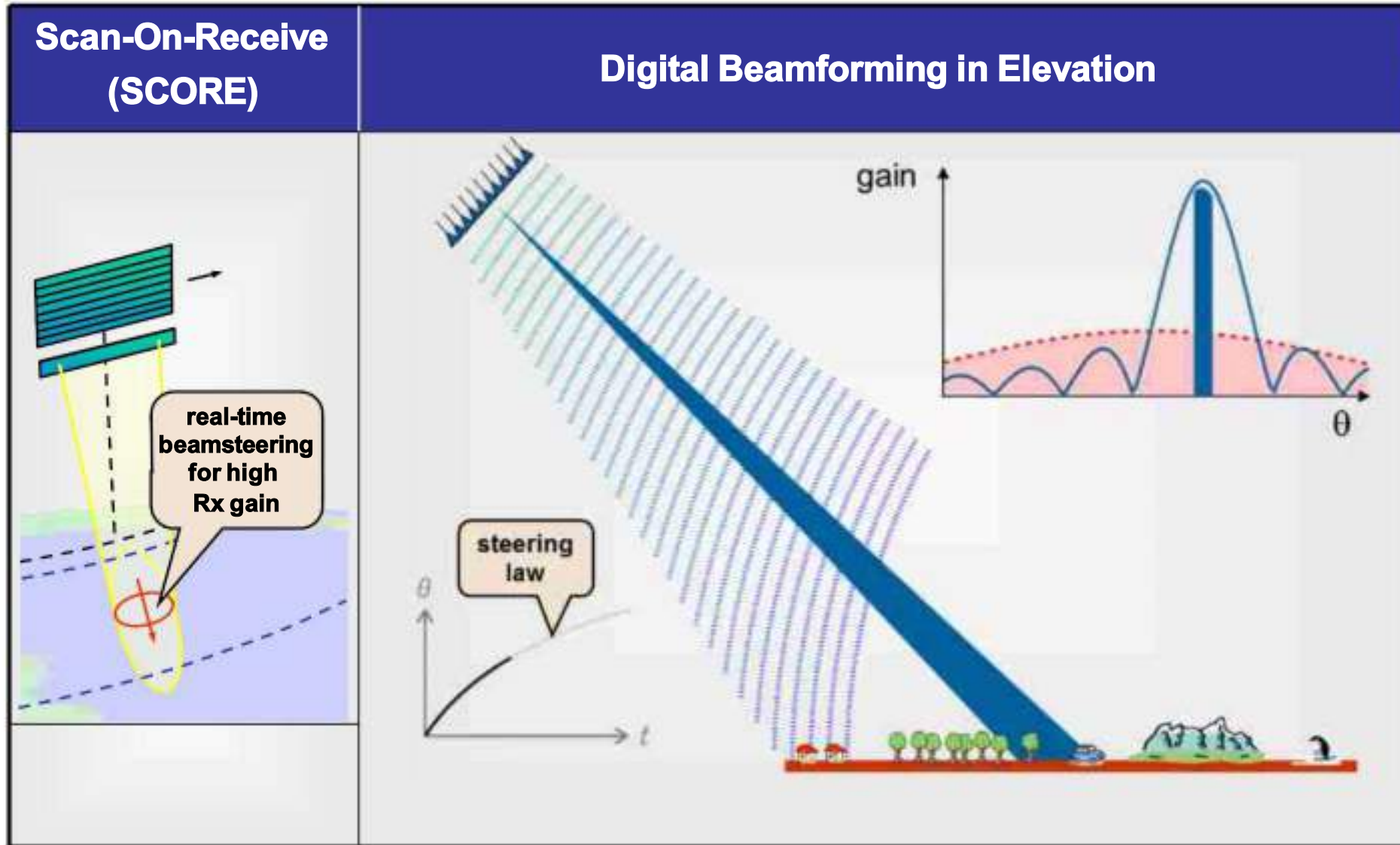


ALOS-4, NISAR,  
ROSE-L,  
Sentinel-1NG,  
Tandem-L, etc.

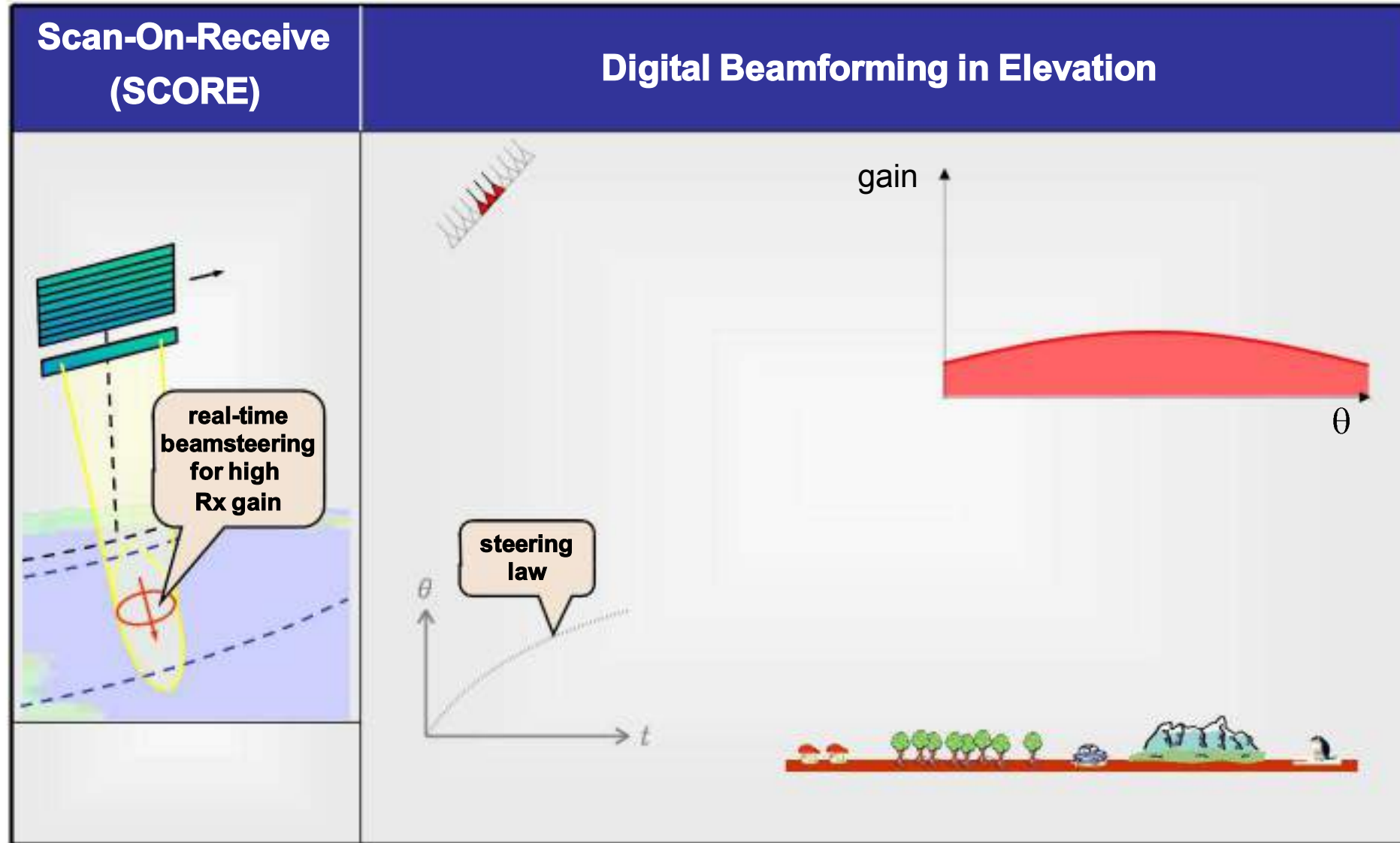




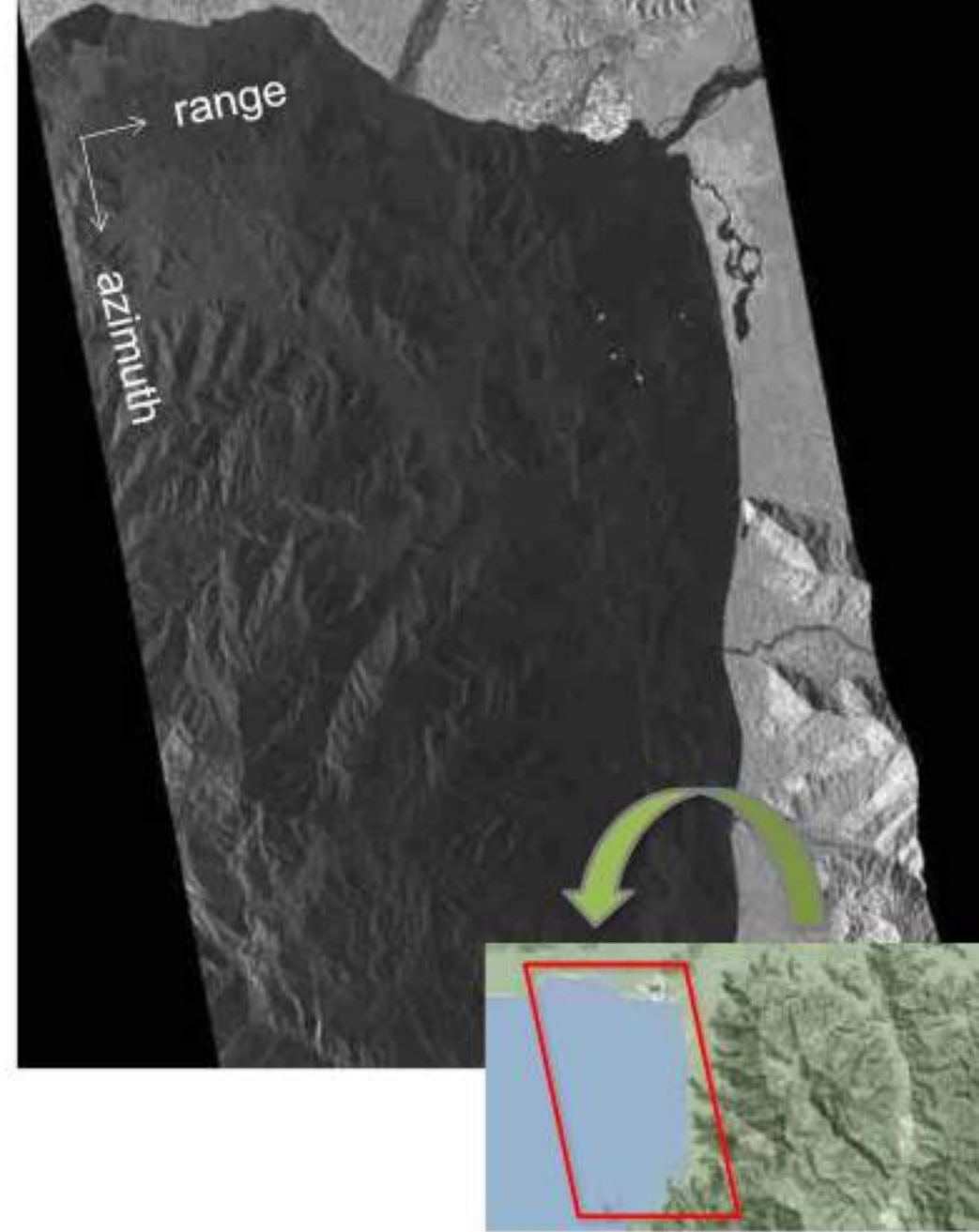
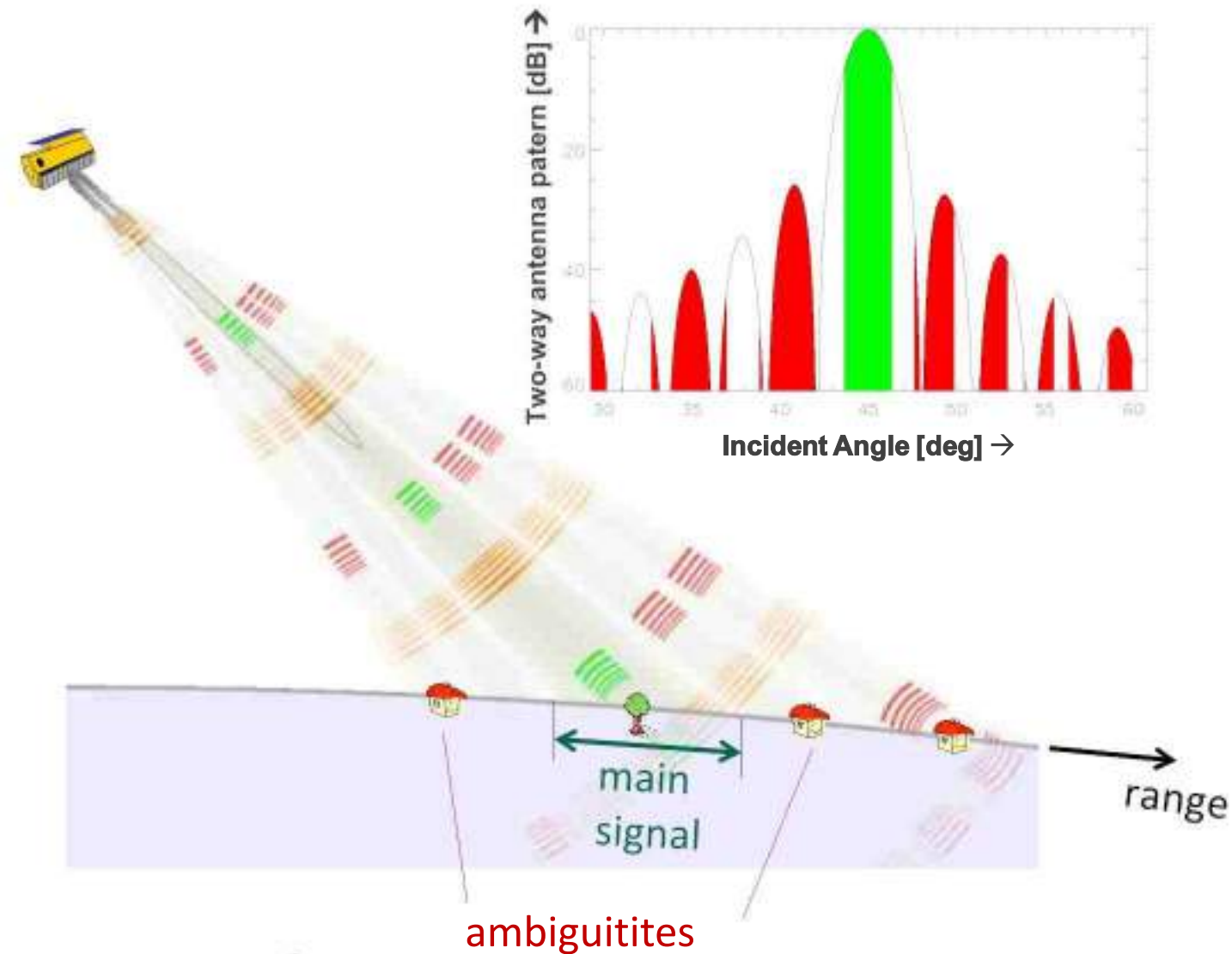
# Digital Beamforming in Elevation



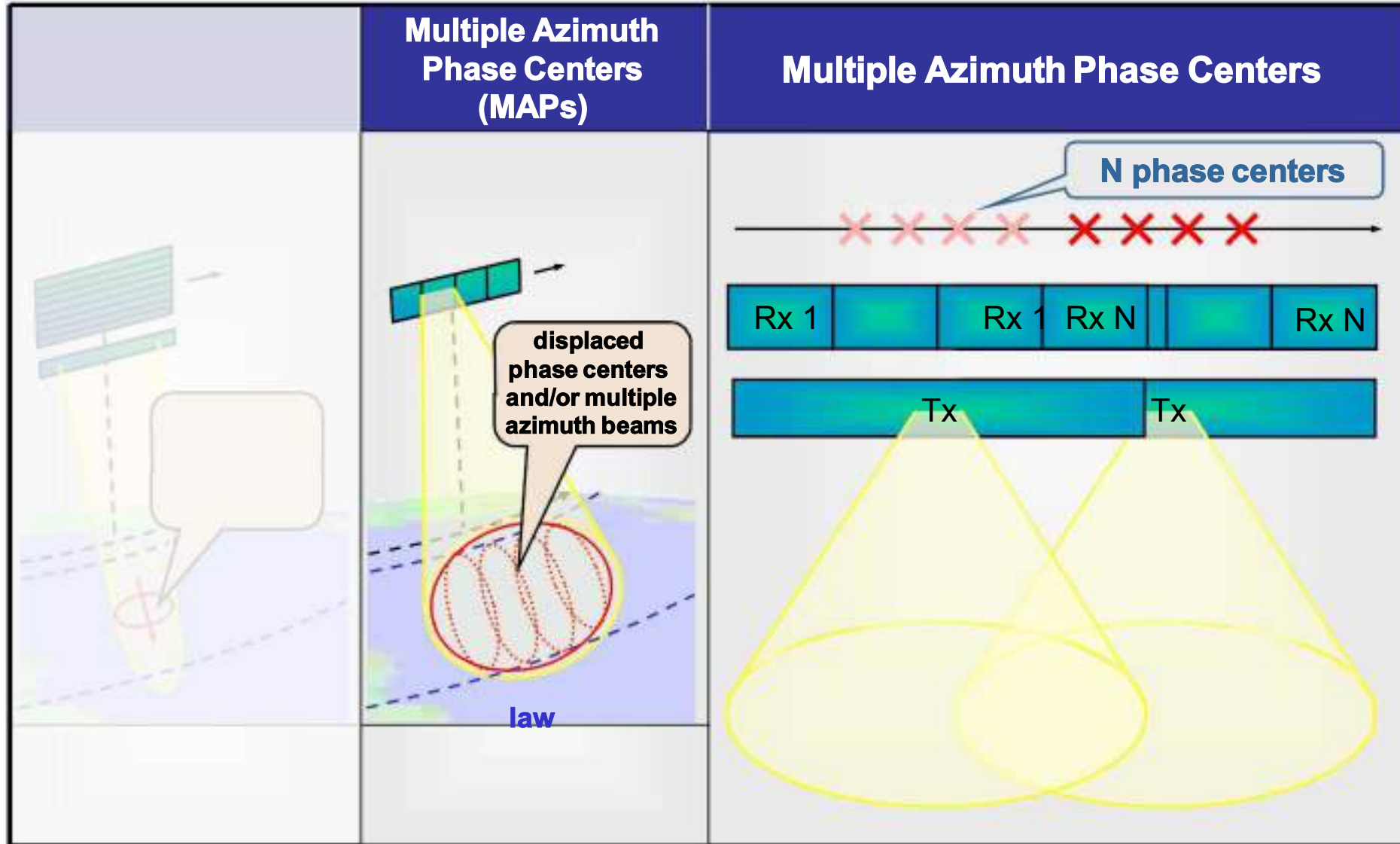
# Digital Beamforming in Elevation



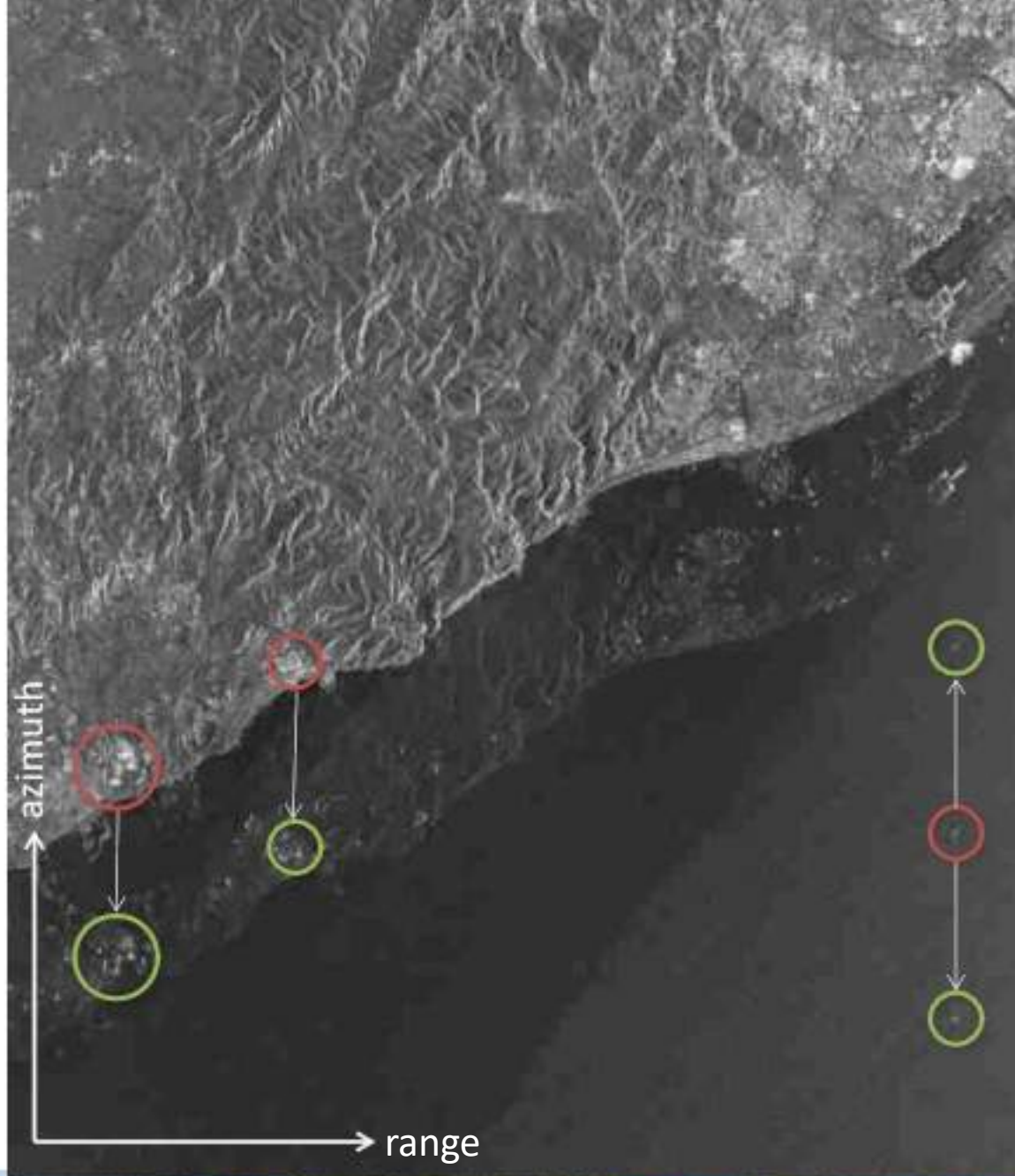
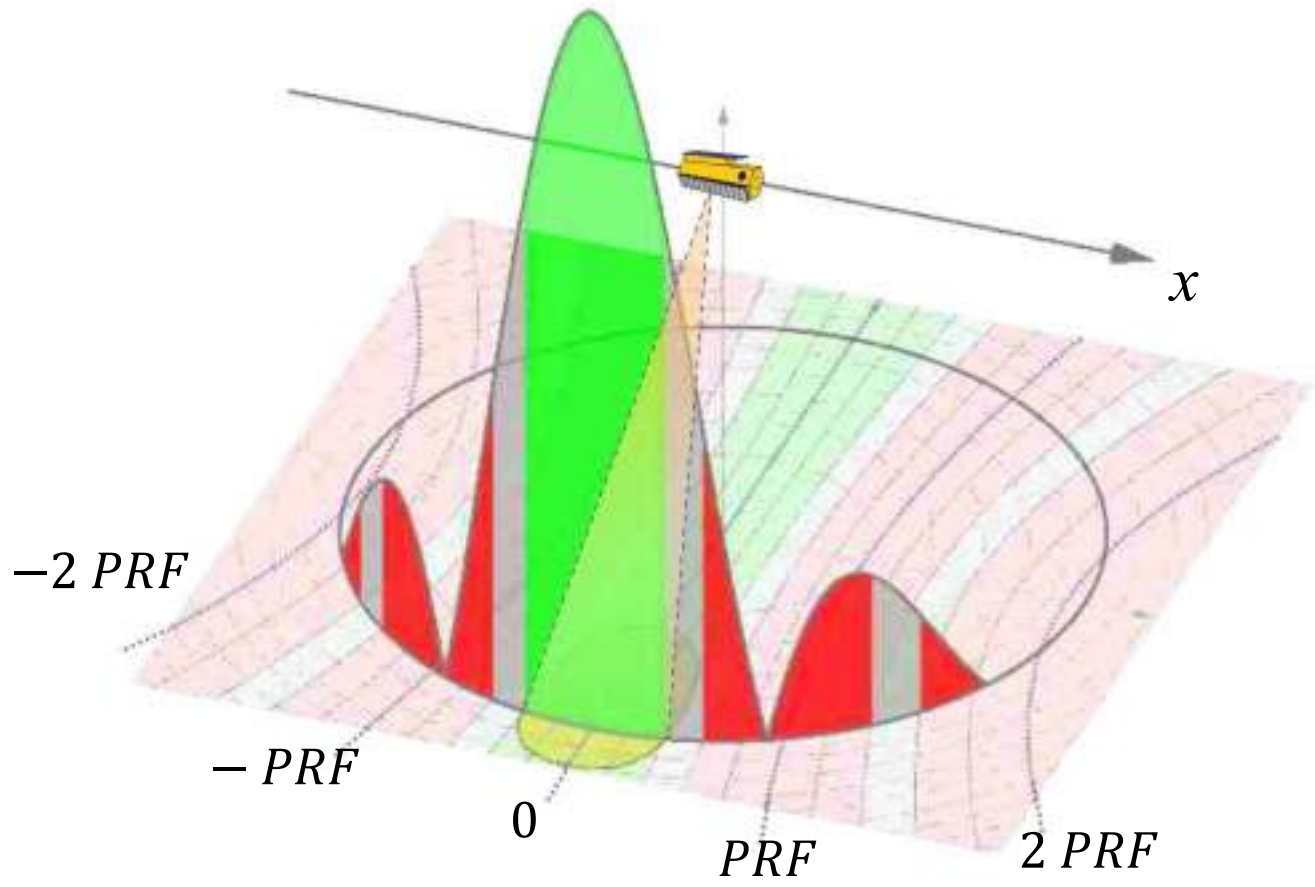
# Range Ambiguities in SAR Systems





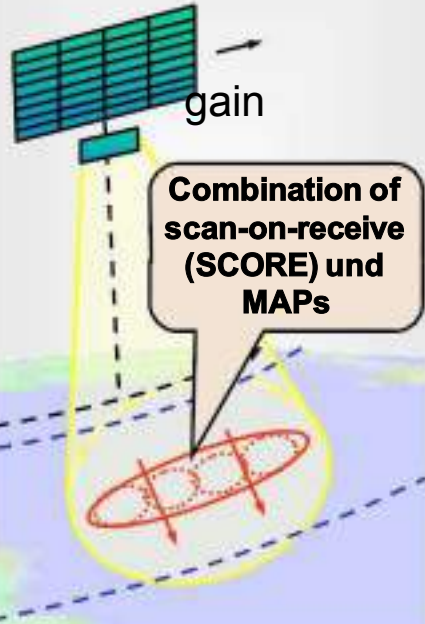
# Digital Beamforming in Azimuth



# Azimuth Ambiguities in SAR Systems

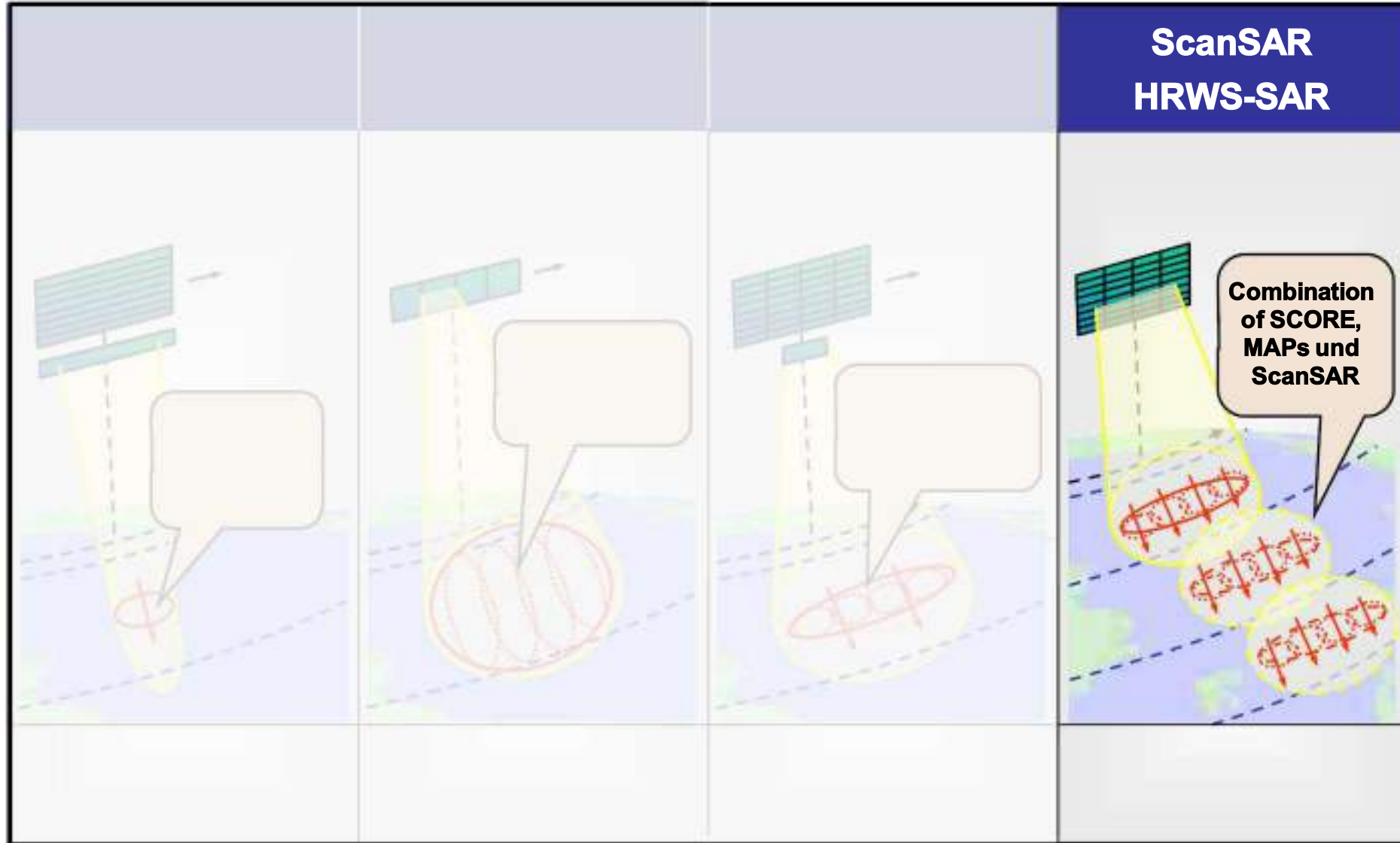


# Digital Beamforming in Elevation and Azimuth

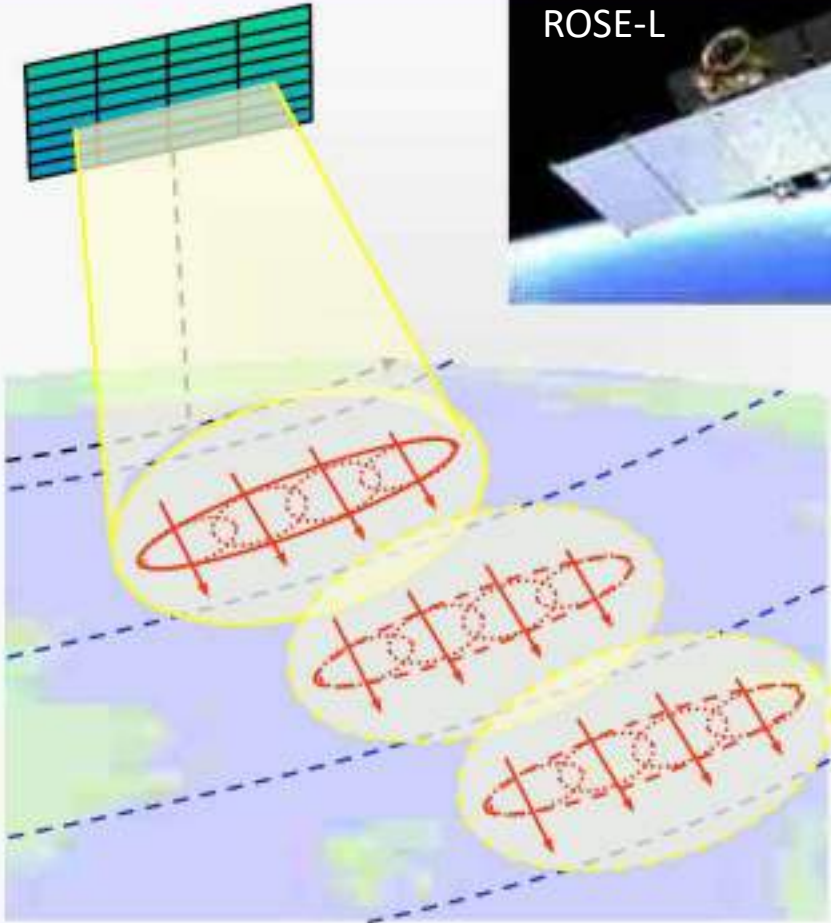
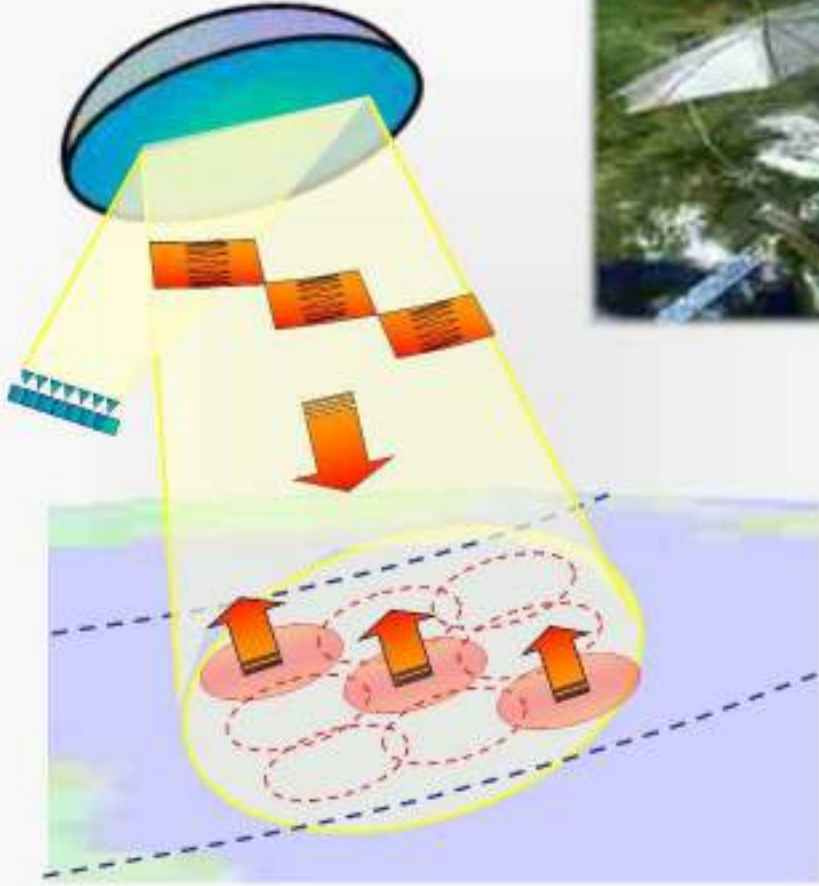
		High Resolution Wide Swath (HRWS)	System Concept Examples												
			<table border="1"> <thead> <tr> <th data-bbox="1753 462 1913 582">swath [km]</th> <th data-bbox="1913 462 2058 582">PRF [Hz]</th> <th data-bbox="2058 462 2181 582"><math>d_{\text{ant}}</math> [m]</th> </tr> </thead> <tbody> <tr> <td data-bbox="1753 582 1913 654">100</td> <td data-bbox="1913 582 2058 654">1600</td> <td data-bbox="2058 582 2181 654"><math>\approx 10</math></td> </tr> <tr> <td data-bbox="1753 654 1913 725">200</td> <td data-bbox="1913 654 2058 725">800</td> <td data-bbox="2058 654 2181 725"><math>\approx 20</math></td> </tr> <tr> <td data-bbox="1753 725 1913 801">400</td> <td data-bbox="1913 725 2058 801">400</td> <td data-bbox="2058 725 2181 801"><math>\approx 40</math></td> </tr> </tbody> </table>	swath [km]	PRF [Hz]	$d_{\text{ant}}$ [m]	100	1600	$\approx 10$	200	800	$\approx 20$	400	400	$\approx 40$
swath [km]	PRF [Hz]	$d_{\text{ant}}$ [m]													
100	1600	$\approx 10$													
200	800	$\approx 20$													
400	400	$\approx 40$													



# Digital Beamforming in Azimuth and Elevation with ScanSAR

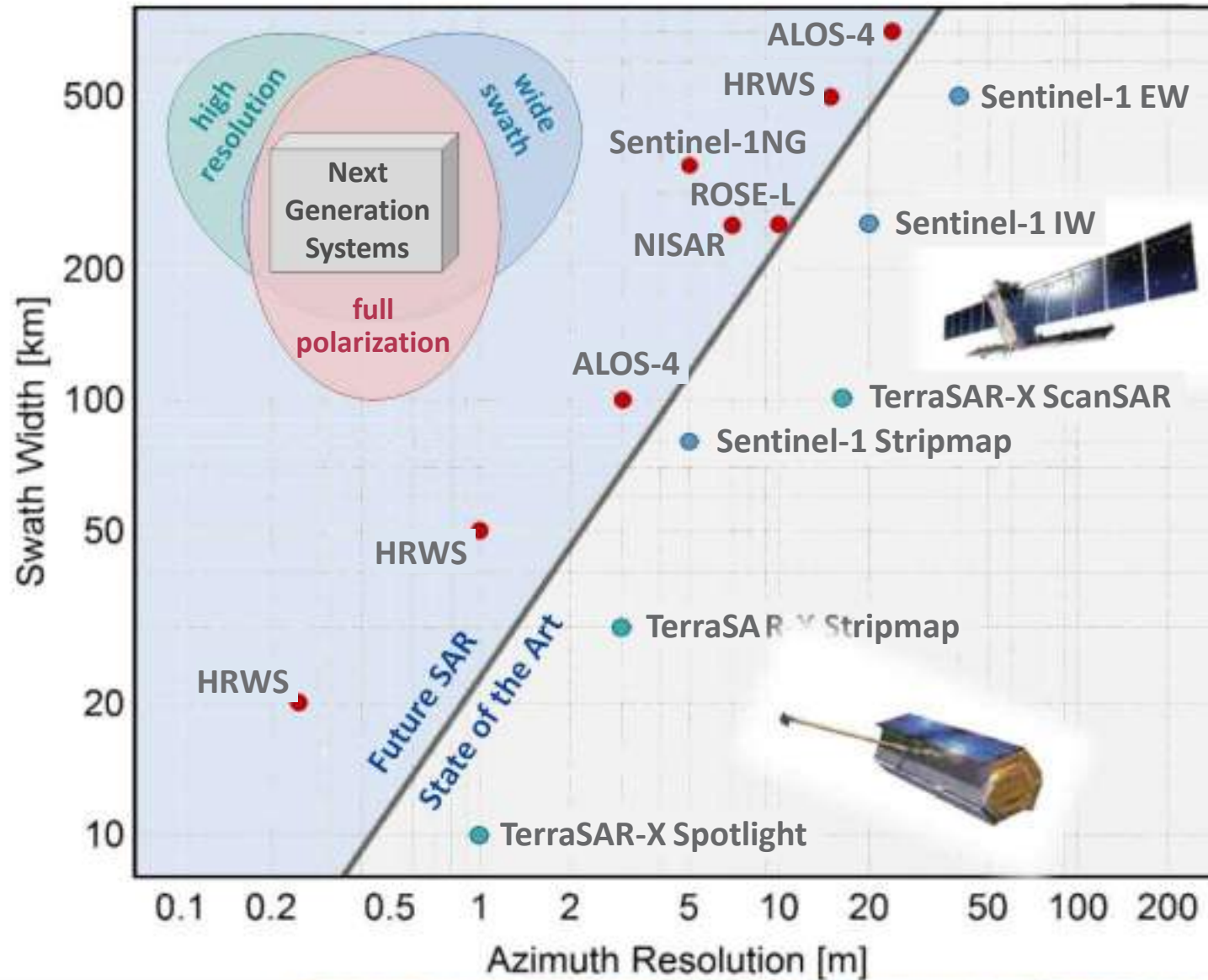


# Digital Beamforming @ Future Spaceborne SAR Systems

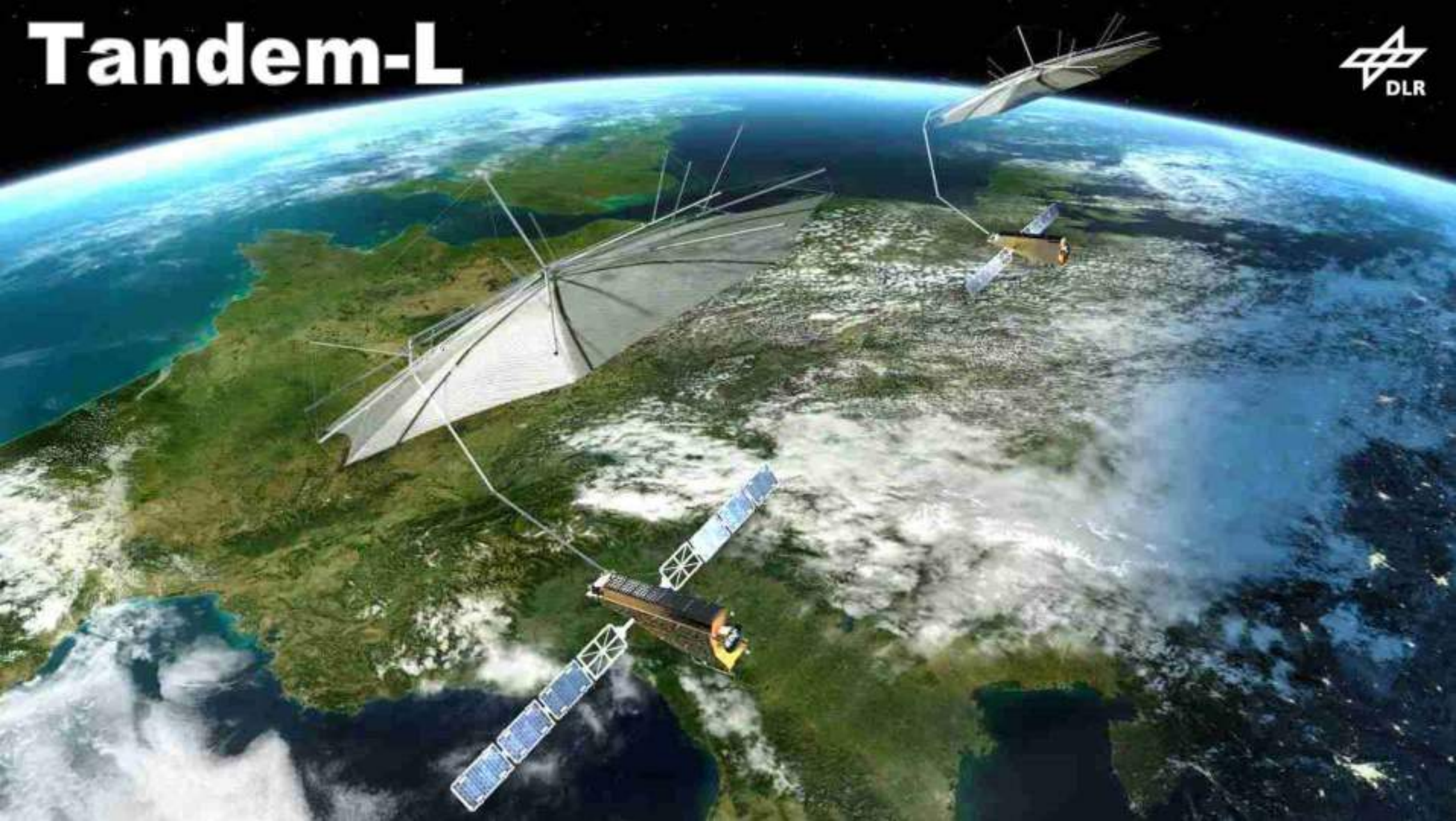
Direct Radiating Arrays	Reflectors with Digital Feed Array
<p data-bbox="861 339 983 372">ROSE-L</p>  <p>The diagram illustrates a direct radiating array system. A green rectangular antenna array is mounted on a satellite platform. A yellow cone represents the radiation pattern, which is directed towards the Earth's surface. Three red dashed ellipses on the ground represent the illuminated area, with red arrows indicating the direction of the radiation. An inset image shows the ROSE-L satellite in orbit above the Earth's horizon.</p>	<p data-bbox="1989 329 2160 362">Tandem-L</p>  <p>The diagram illustrates a reflector system with a digital feed array. A blue circular feed array is mounted on a satellite platform. A yellow cone represents the radiation pattern, which is directed towards a large, flat reflector on the satellite. The radiation is then reflected down to the Earth's surface. Three red dashed ellipses on the ground represent the illuminated area, with red arrows indicating the direction of the radiation. An inset image shows the Tandem-L satellite in orbit above the Earth's horizon.</p>



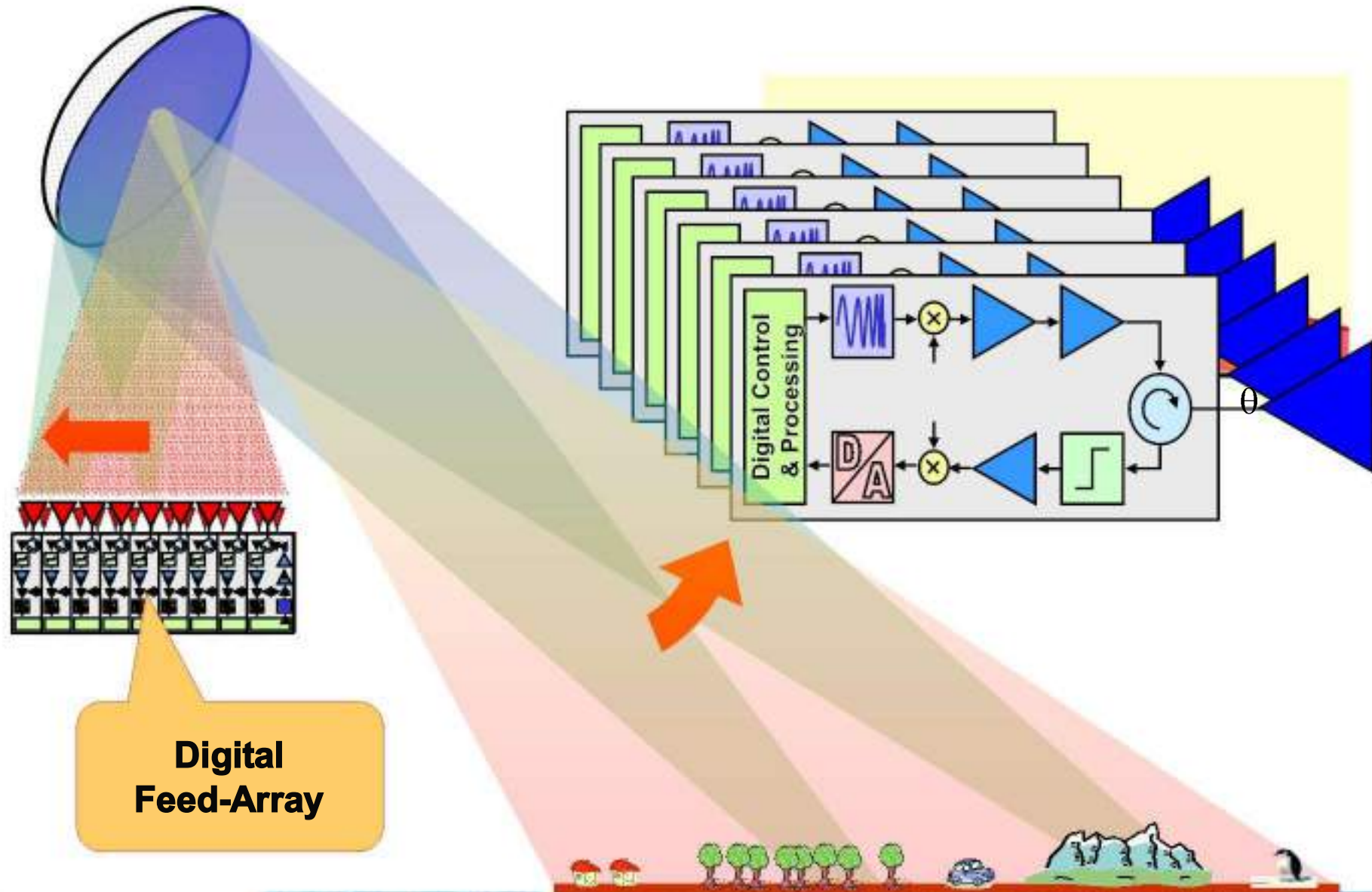
# Digital Beamforming @ Future Spaceborne SAR Systems



# Tandem-L

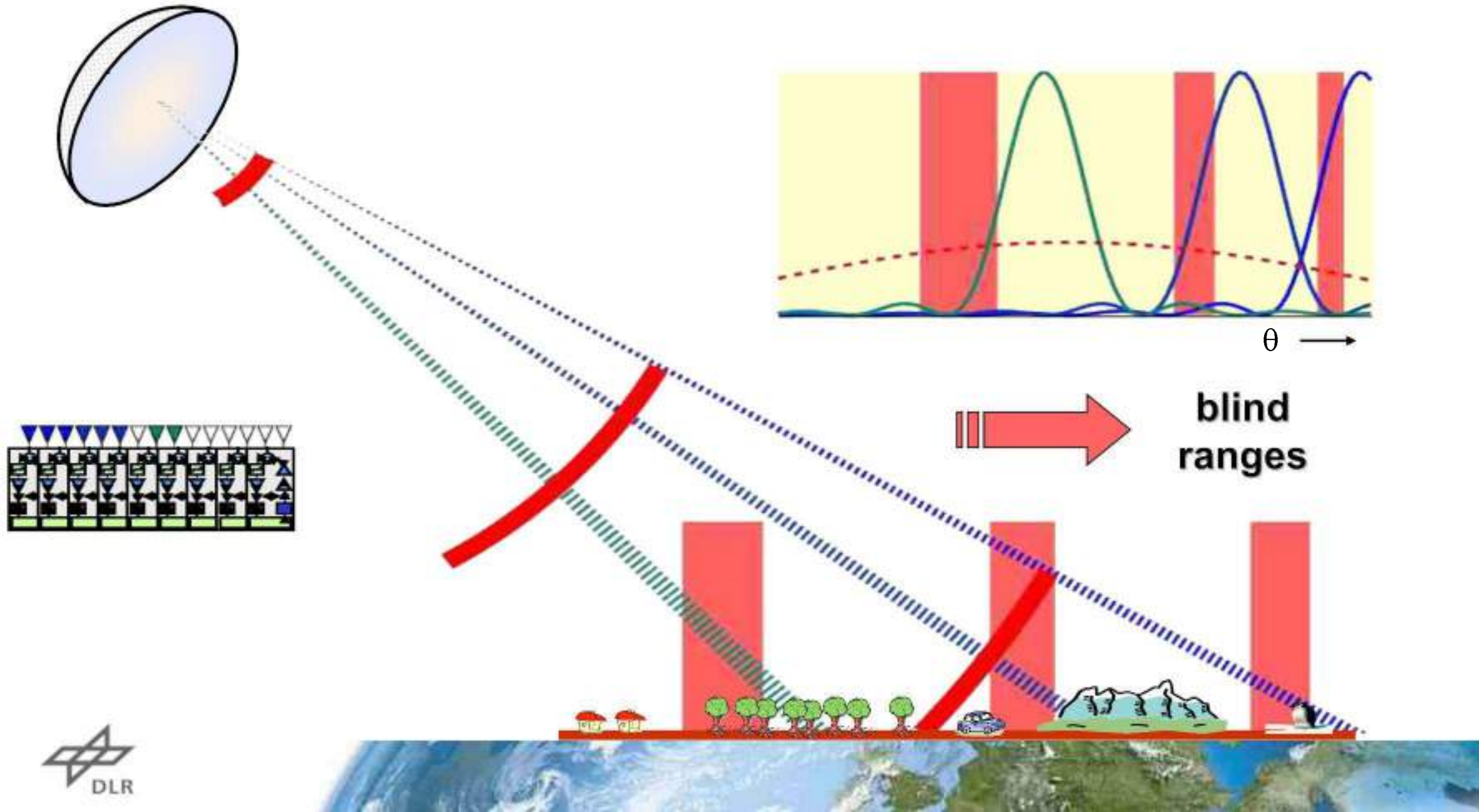


# Digital Beamforming with Large Reflector Antenna



**Digital  
Feed-Array**

# Digital Beamforming with Large Reflector Antenna



# Comparison of Imaging Capacity

TerraSAR-X/TanDEM-X

1 global coverage / year



Digital Beamforming (Tandem-L)

2 global coverages / week



1

Days



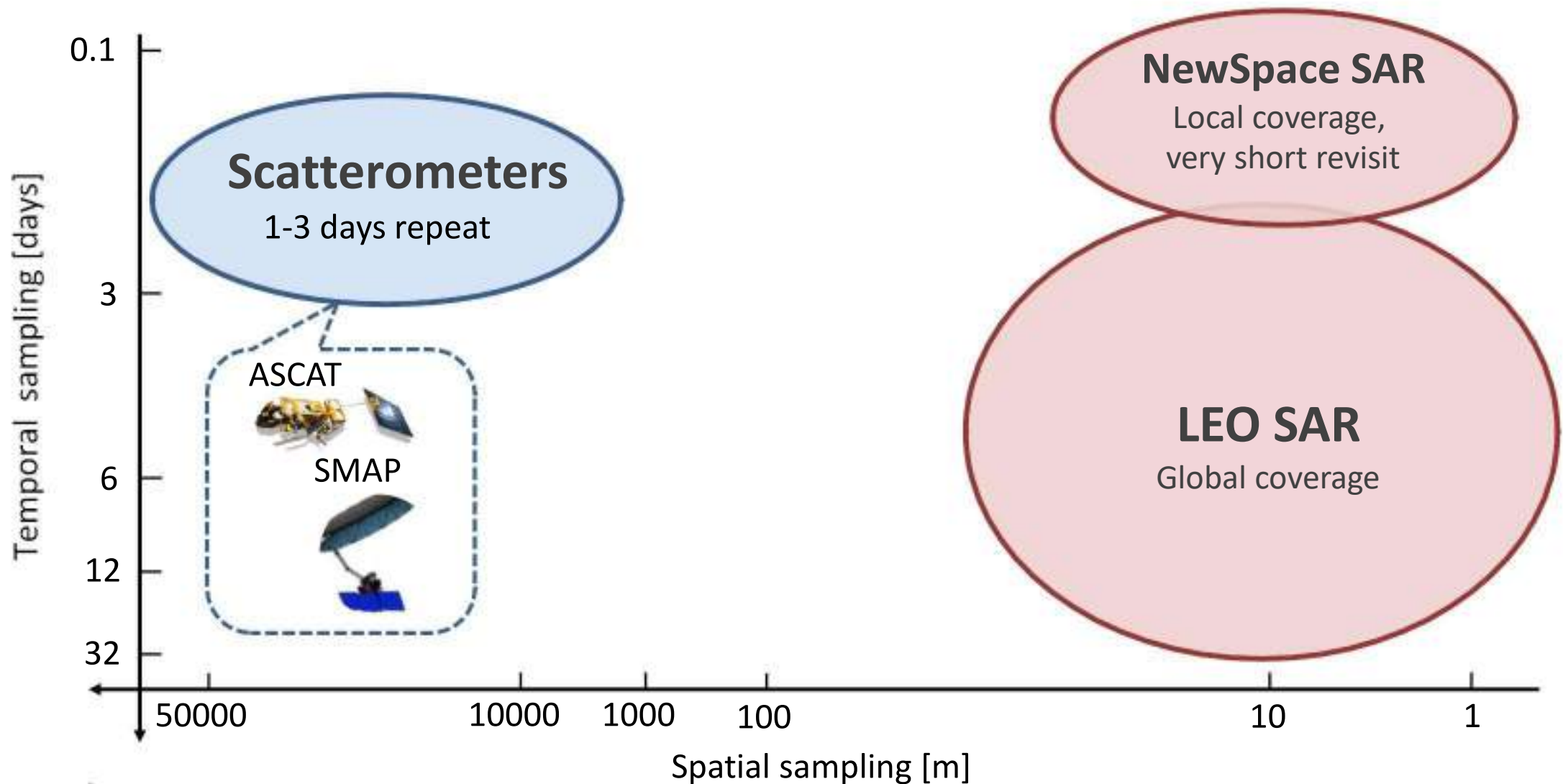
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# NewSpace @ SAR Remote Sensing

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# Spaceborne Radar for Earth Observation



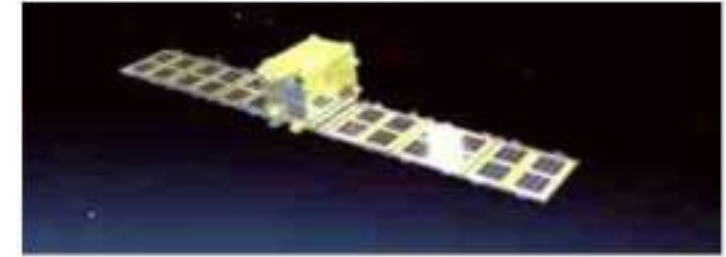
# NewSpace @ SAR Remote Sensing



ICEYE, Finland  
30+ (20) Satellites



Capella, USA  
36 (7) Satellites



Synspective, Japan  
30 (3) Satellites



Xpress SAR, USA  
3/4 Satellites



iQPS Inc., Japan  
36 (2) Satellite



HRWS MirrorSAR, Germany  
3 - 4 Small Satellites



Spacety, China/Luxembourg  
C- and X-band, 56 (1) Satellites



Umbra SAR, USA  
24 (1) Satellites

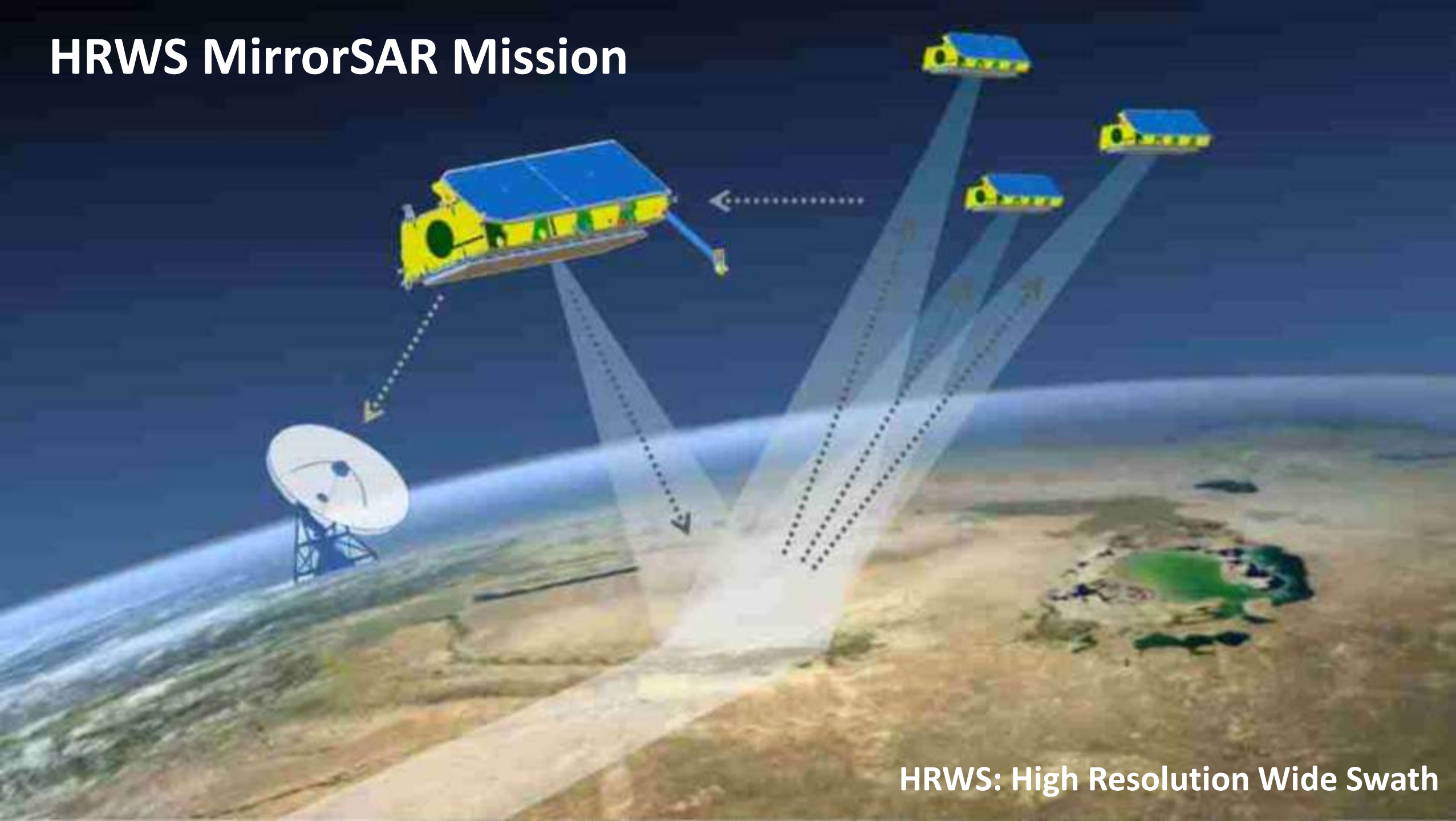


PredaSAR, USA  
96 Satellites





# HRWS MirrorSAR Mission

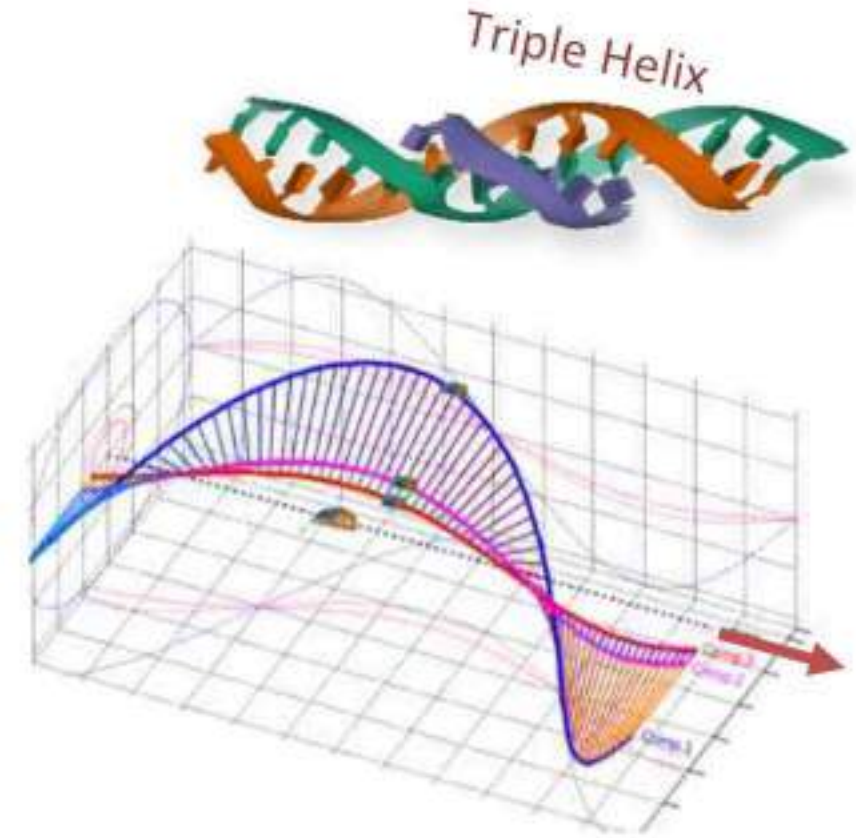
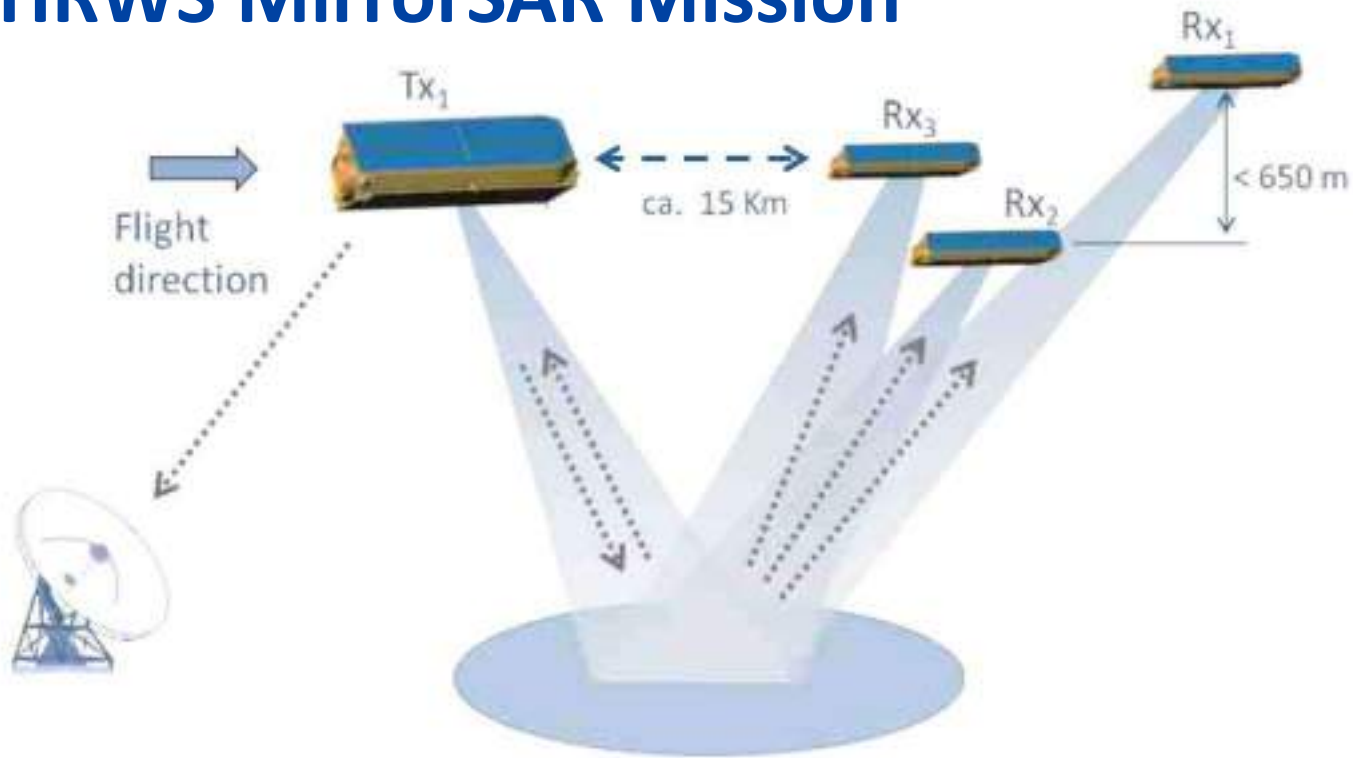


HRWS: High Resolution Wide Swath



**Kaufbeuren (Germany)**  
DBFSAR, X Band quadpol  
0.25 m x 0.25 m resolution

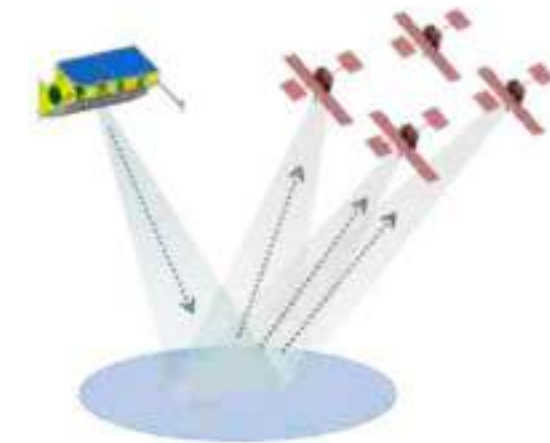
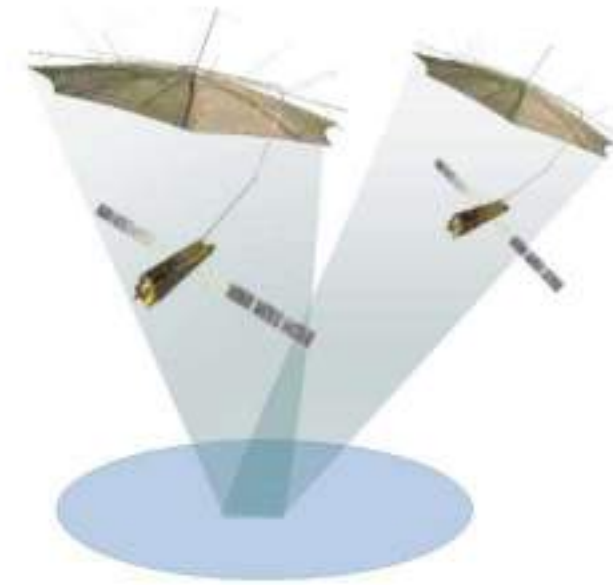
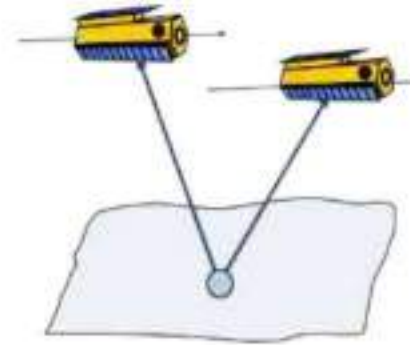
# HRWS MirrorSAR Mission



Imaging mode	HRWS MirrorSAR	TerraSAR-X TanDEM-X	Benchmark
Spotlight	0.25 m x 0.25 m @ 400 km <sup>2</sup>	0.25 m x 1 m @ 15 km <sup>2</sup>	106
Stripmap Single Pol	1 m x 1 m @ 80 km	3 m x 3 m @ 30 km	24
Stripmap Quad Pol	2 m x 2m @ 50 km	3 m x 6 m @ 15 km	15
3D Imaging	4 m x 4 m x 2 m	12 m x 12 m x 2 m	9

# Trends for SAR Remote Sensing

- High-performance SAR systems
  - High resolution ( $< 5$  m), wide swath ( $> 400$  km)
  - Global coverage, short revisit
  - Digital beamforming (planar or large reflector antenna)
  - Bistatic/multistatic SAR systems with enhanced capabilities (e.g. polarimetry, interferometry and tomography)
- Small satellites (e.g., NewSpace)
  - Low costs (small swath, but high resolution)
  - Focused applications, small coverage, but very short revisit
  - Combination with high performance SAR systems
  - Distributed SAR systems



# Spaceborne Radar for Earth Observation

