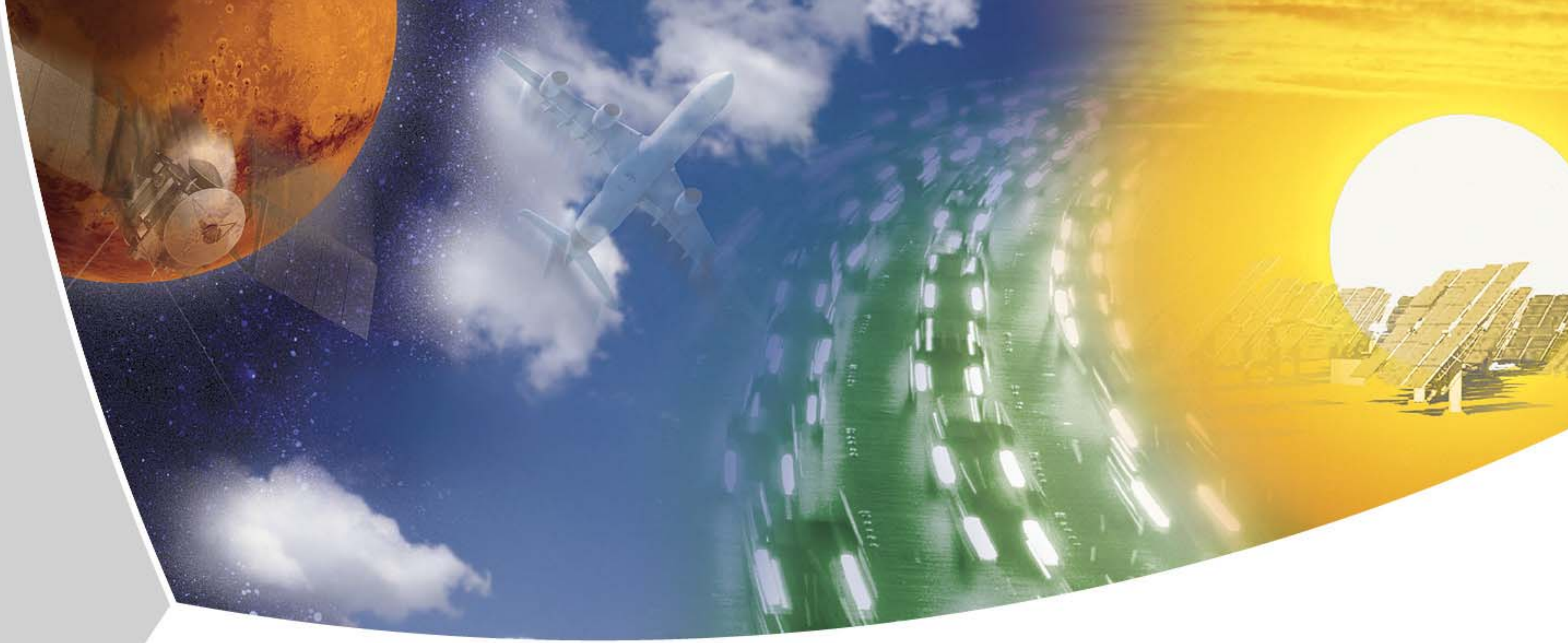


Constellation & Formation Flying Concepts for Radar Remote Sensing

H. Fiedler, G. Krieger, M. Zink

Future SAR Systems: Motivation

Application Areas for SAR Data Products

Agriculture


Precision Farming Suite
Crop Ripeness
Crop Inventory
Yield Prediction Cereals

Risk / Disaster

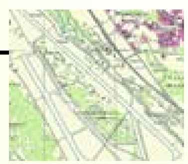

Flood Damage Assessment
Fire Damage Assessment
Storm Damage Assessment

Forestry


Strategic Forestry Inventory
Reconnaissance Inventory
Inventory Update

Security


Reconnaissance Imagery (VHR-SAR)

Cartography


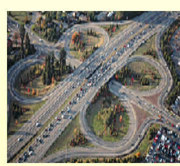
Topo Map
Regional Planing Map
Environmental Planing Map
Infrastructure Planing Map

Geology


Geology Structure Map
Geology Image Map
Geology Elevation Map
Oil Seep Detection

Marine

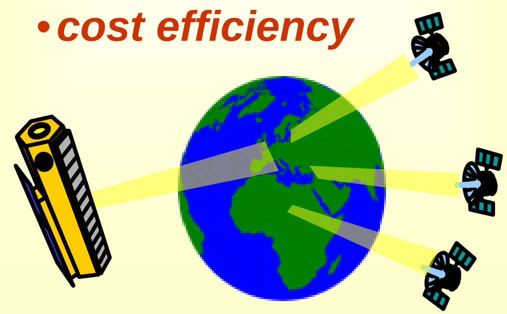

Ship Detection Service
Oil Spill Monitoring
Sea Ice Monitoring

Transportation


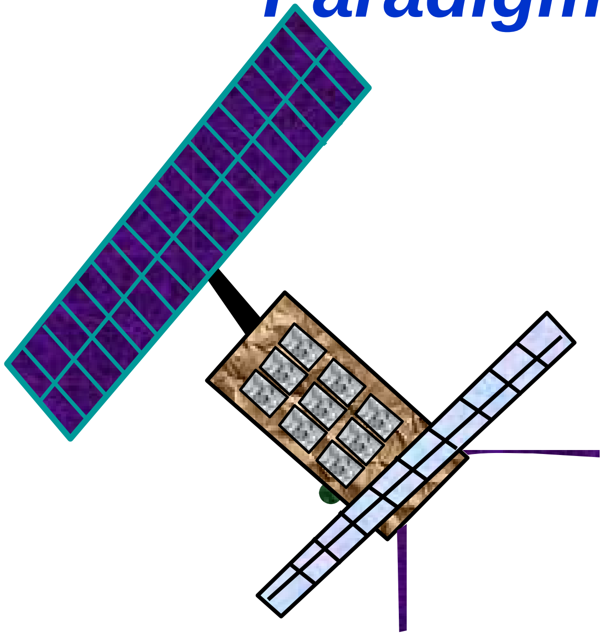
Dynamic Traffic Monitoring
Maps of Roads, Channels, ...

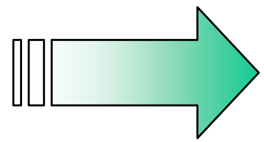
System Requirements

- *short response time*
- *high revisit frequency*
- *wide area coverage*
- *high radiometric and geometric resolution*
- *imaging with multiple*
  - *polarisations*
  - *wavelengths*
  - *view angles (e.g. interferometry)*
  - *time intervals (change detection)*
- *high reliability*
- *cost efficiency*

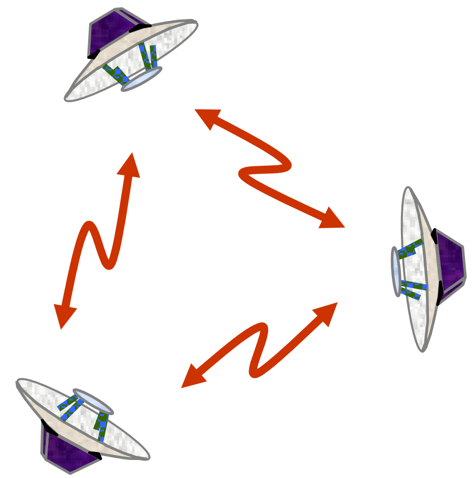


Future SAR Systems:
Paradigm Shift to Satellite Clusters





Paradigm Shift



Large, multi-functional satellites

Virtual satellite -
web of cooperating satellites

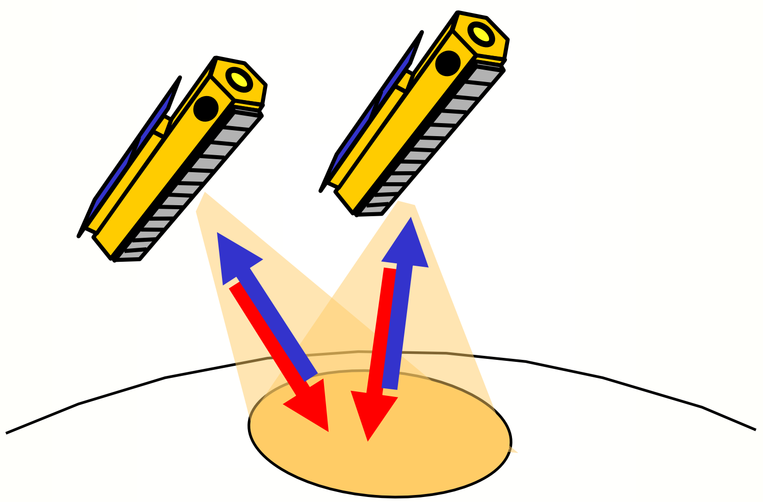
- Smaller, simpler satellites → reduced cost & time
- Modular design → upgradable, improved reliability
- Spatially distributed → improved revisit time / coverage / adaptability
- Separated, sparse apertures → improved performance and resolution

Bistatic and Multistatic SAR Systems

Definitions:
- Radar systems with a spatial separation between transmitter and receiver are called ***bistatic***.
- Systems with multiple receivers are called ***multistatic.***

Fully active system

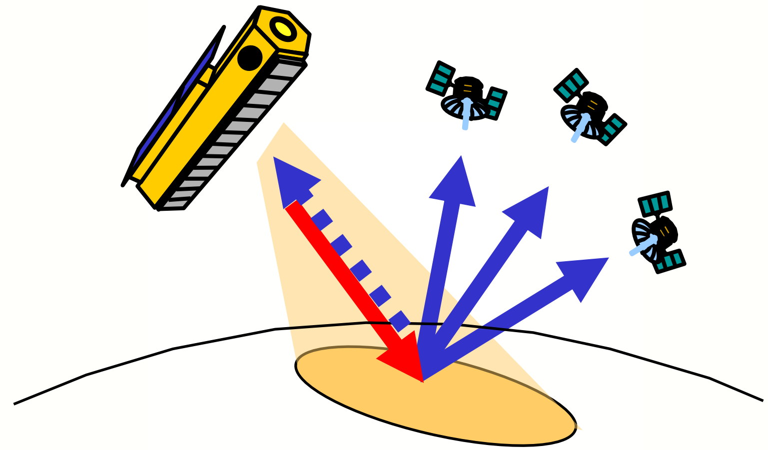
(TechSAT21, Radarsat 2/3, TanDEM-X)



+ two monostatic & two bi-static images
+ phase synchronisation in ping/pong mode
+ higher redundancy & increased flexibility

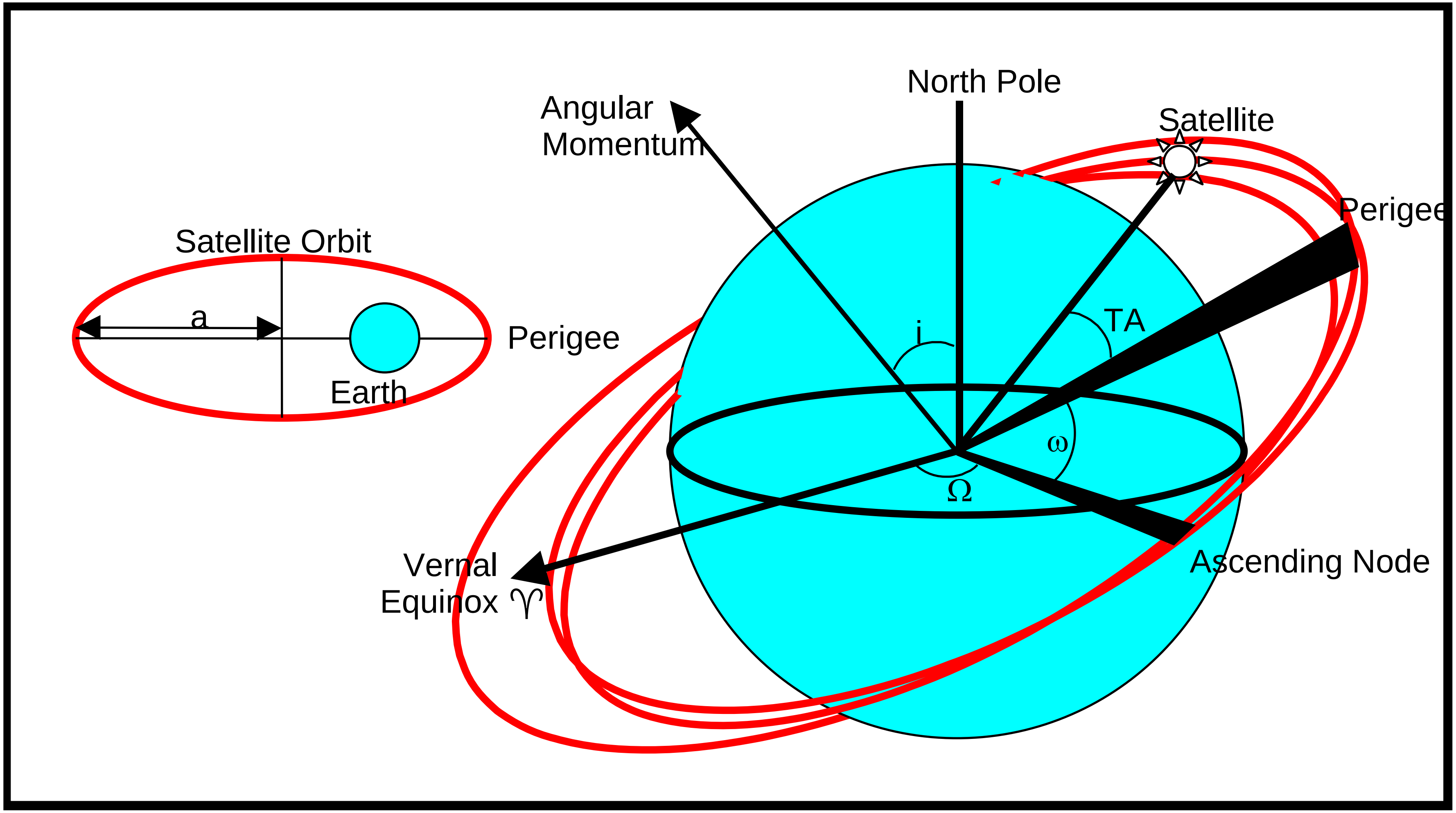
Partially active system

(BISSAT, Cartwheel, Cross-Track Pendulum)

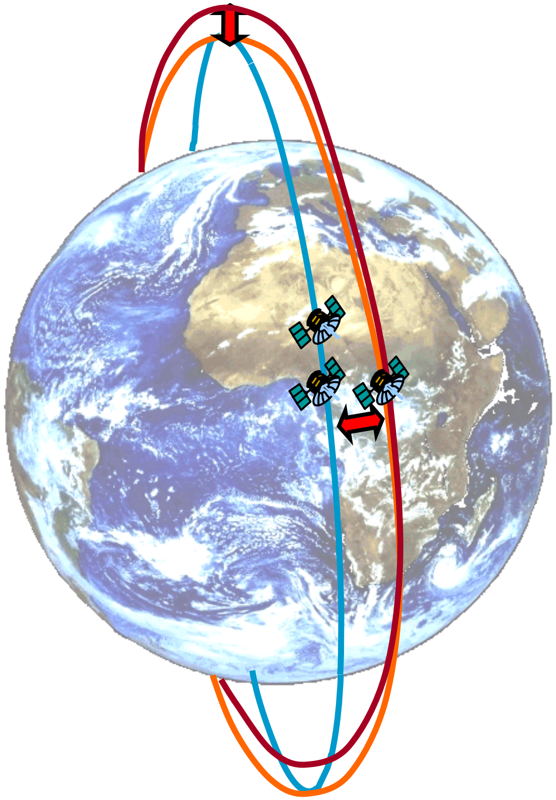


+ reduced costs & low weight of passive receivers
+ increased sensitivity (no Tx/Rx switches)
+ DBF on receive with MMICs in the antenna

Changeable Orbital Parameters



How Do They Look Like?

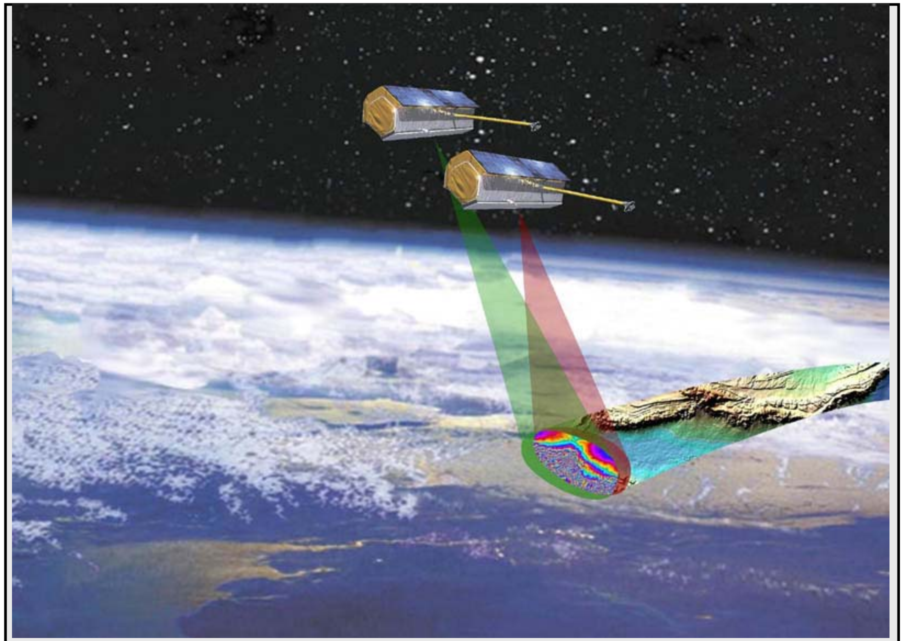


Two satellites orbit behind each another with

- different ascending nodes:
  - collision riks
  - no cross track baselines at high latitudes
- additional different eccentricities (HELIX)
  - safe operation
  - arbitrary shift in along track

Twin Satellite Formation: HELIX

- Two satellites with different right ascensions of the ascending node
- Equal inclination for both satellites
- Two completely spatially separated orbits avoid collision (e/I vect)
- Along-track displacement selectable at desired latitude
- Shift of ascending nodes or expansion of eccentricity required for cross track interferometry at high latitudes
- First implementation of operational close formation flight expected in spring 2009 with TanDEM-X for global DEM-derivation



- TerraSAR-X Add-on for Digital Elevation Measurements
- PPP Astrium/DLR

Bistatic and Multistatic SAR Systems

Definitions:
- Radar systems with a spatial separation between transmitter and receiver are called ***bistatic***.
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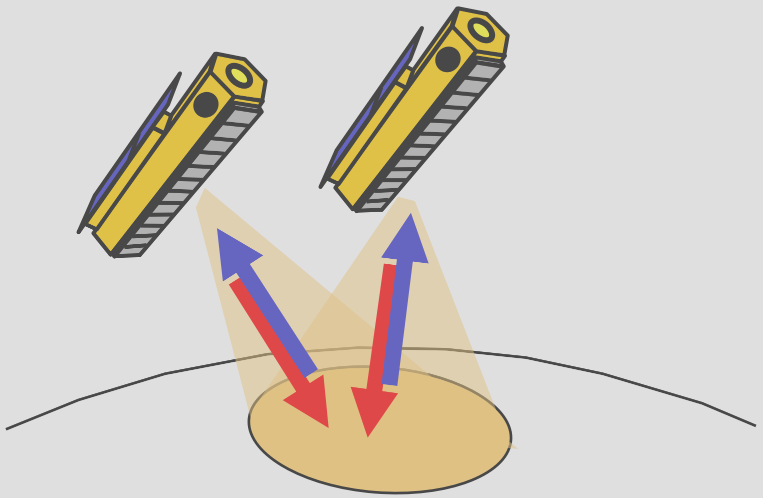
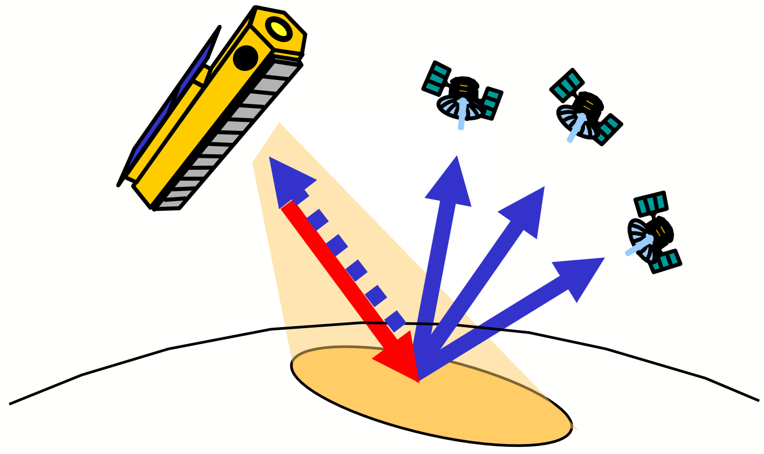


- \+ two monostatic & two bi-static images
- \+ phase synchronisation in ping/pong mode
- \+ higher redundancy & increased flexibility

Partially active system

(BISSAT, Cartwheel, Cross-Track Pendulum)



- \+ reduced costs & low weight of passive receivers
- \+ increased sensitivity (no Tx/Rx switches)
- \+ DBF on receive with MMICs in the antenna

Possible Formations

Variation of

Inclination → **Drift**

Right asc. of the asc. node

Argument of perigee → **Drift**

Eccentricity → **Drift**

Pendulum

Trinodal Pendulum

Cartwheel

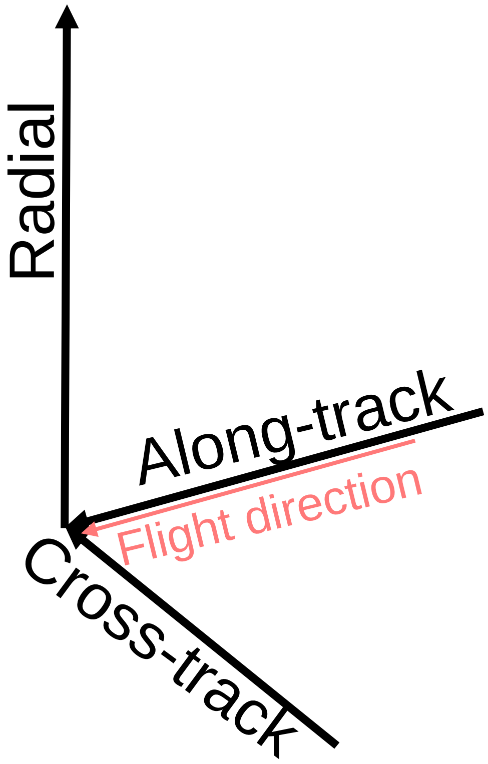
CarPe

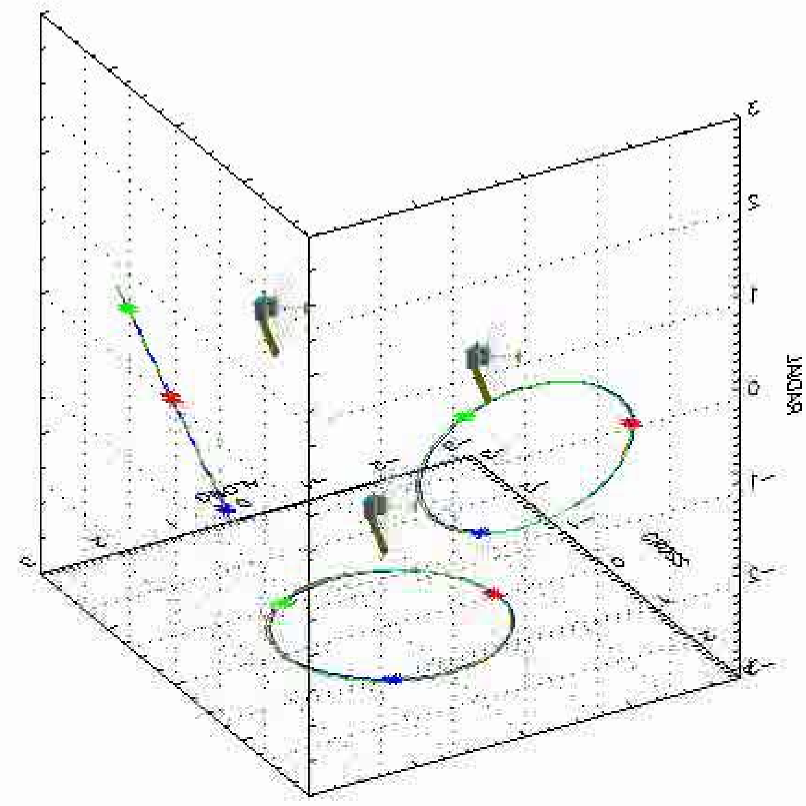
Techsat Circle

HELIX

Example: TechSat Circle

Co-ordinate System is co-rotating in barycentre of formation





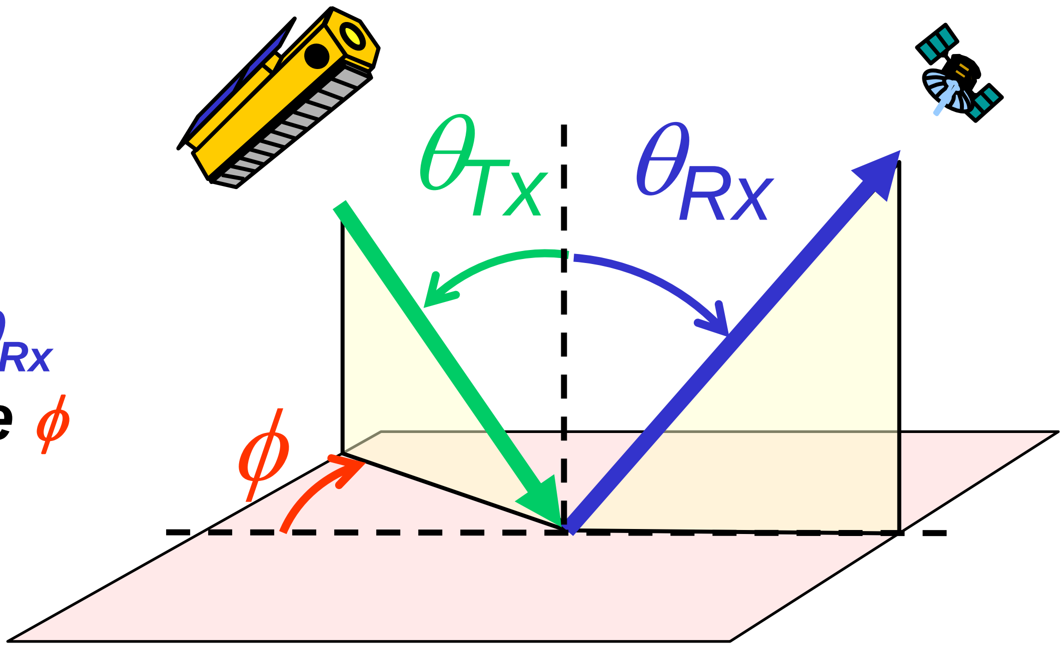
Baselines & Critical Issues

	CT-Pendulum	TN-Pendulum	CarPe	CartWheel	TechSAT-C
Cross	One stable baseline for all orbital positions	Two scalable baselines with constant baseline ratio	One stable baseline for all orbital positions	One stable baseline for all orbital positions	One stable baseline for all orbital positions
Along	Two different baselines independently selectable	Two different baselines independently selectable	One baseline selectable	Constant baseline change	Constant baseline change
Critical	Fuel required to compensate nodal drift	Along track separation of satellites may be critical w/o autonomous control or e/i-vector separation	Reduced common Doppler bandwidth for large baselines at high latitudes	Reduced common Dop. bandwidth for large baselines at all latitudes and along track displacement requires frequent manoeuvring	Reduced common Dop. Bandwidth for large baselines Displacements & nodal drift require frequent manoeuvring

Bistatic Scattering Coefficient

Bistatic scattering depends on:

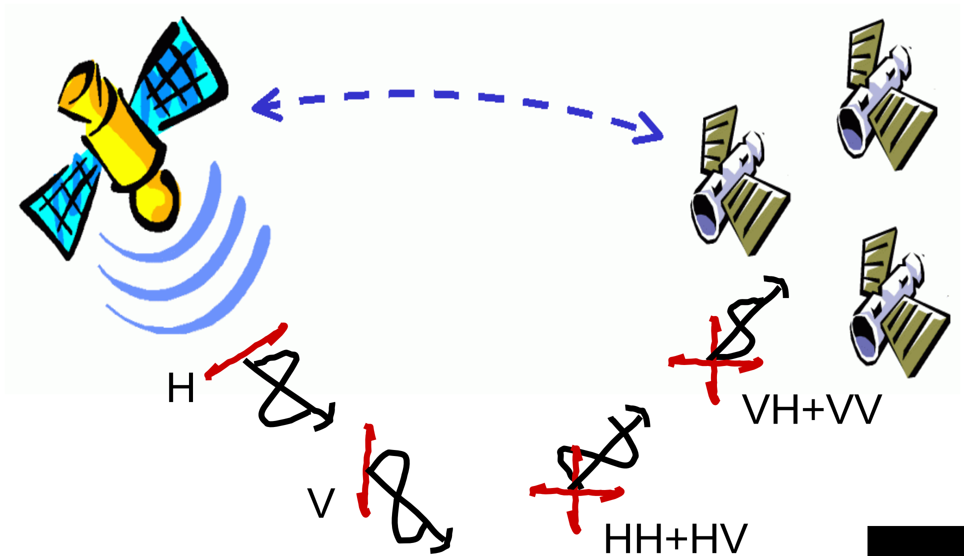
- *Incident angle θ_{Tx}*
- ***Scattering angle θ_{Rx}***
- ***Out-of-plane angle ϕ***
- *Frequency*
- *Polarization*



<u>Extended Observation Space:</u>

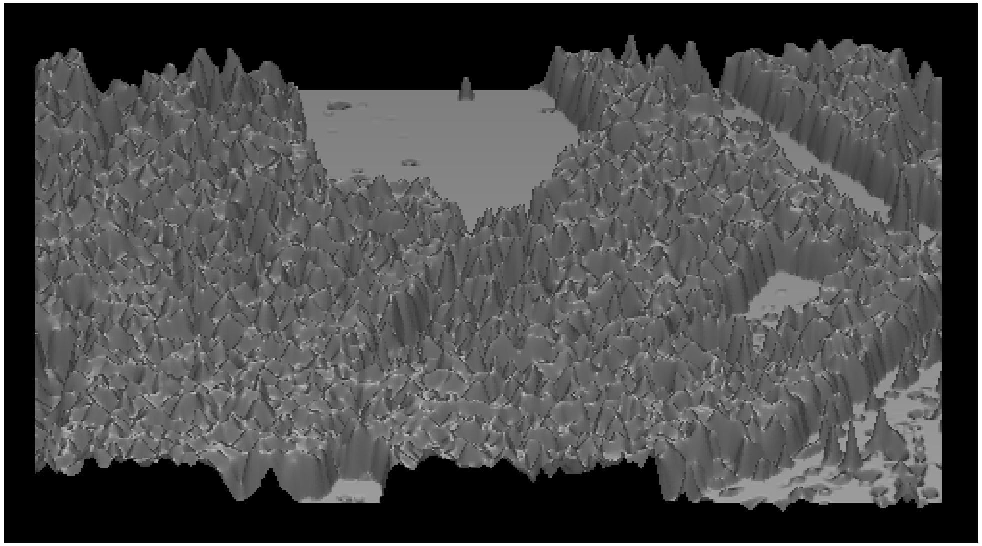
- *improved detection*
- *improved segmentation*
- *improved classification*

Polarimetric Interferometry



Inversion of Coherent Scattering Model
(e.g. Random Volume + Ground)

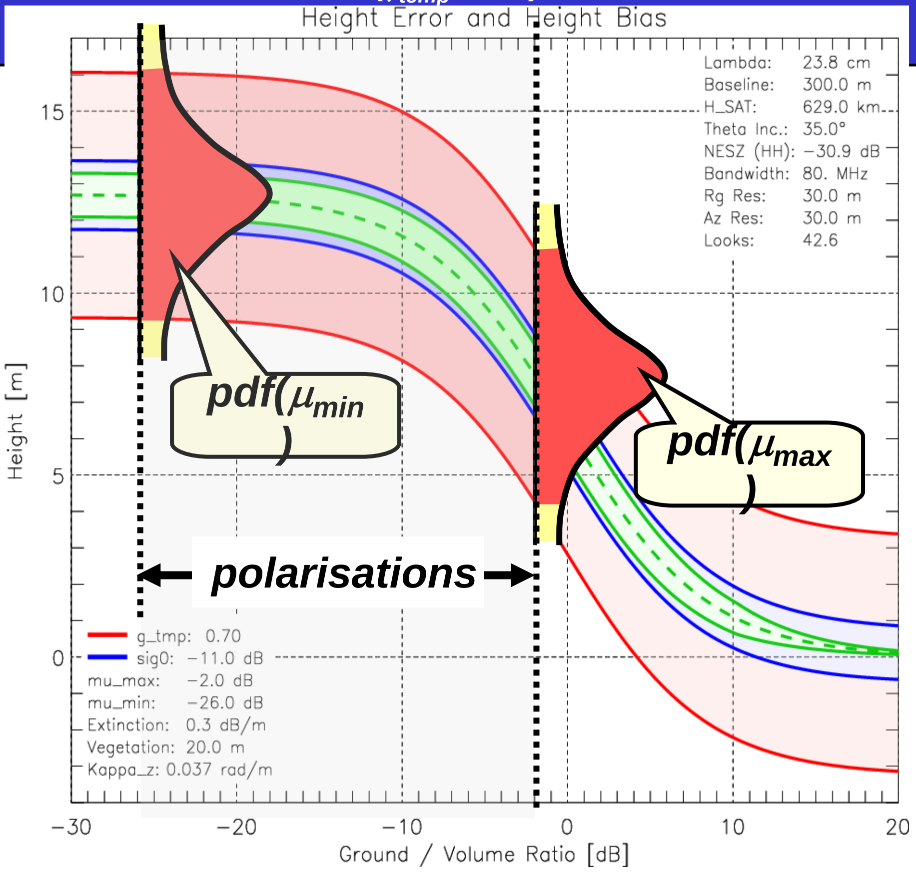
$h_V, \sigma, \phi_0, m_{1-3}$



(from K. Papathanassiou & S. Cloude, 2001

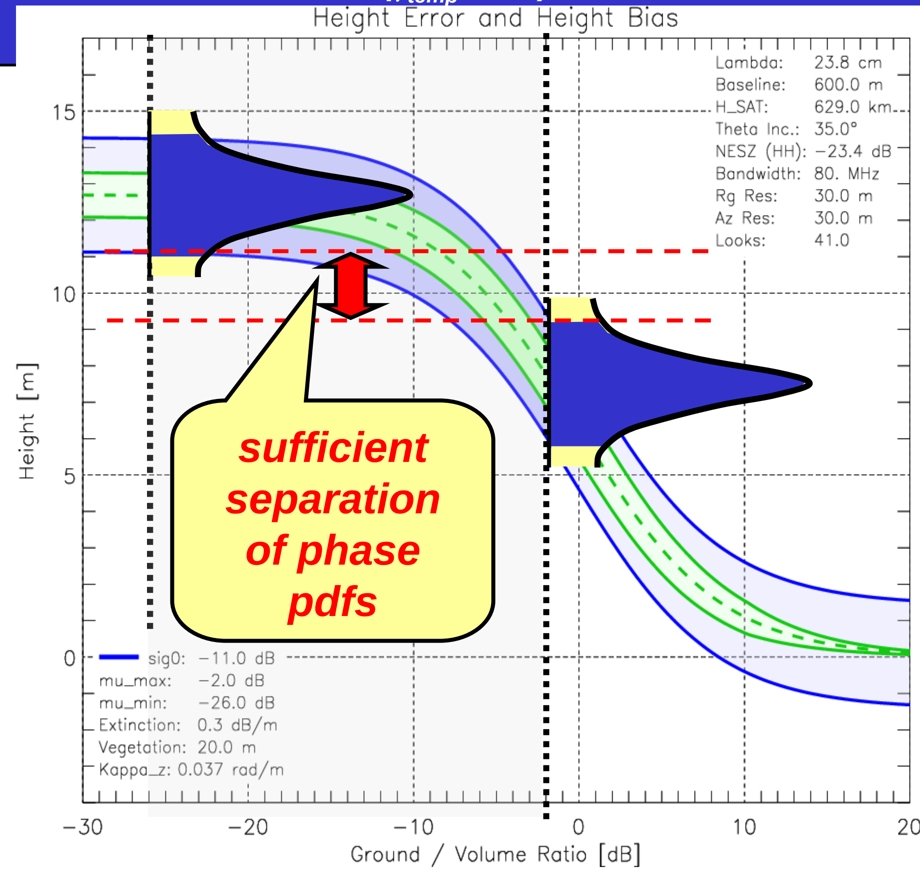
Polarimetric SAR Interferometry: Performance Example for TerraSAR-L

Monostatic Repeat Pass System (γ_{temp} = 0.7)



→ *Poor Inversion Accuracy*

Bistatic Single Pass System (γ_{temp} = 1.0)

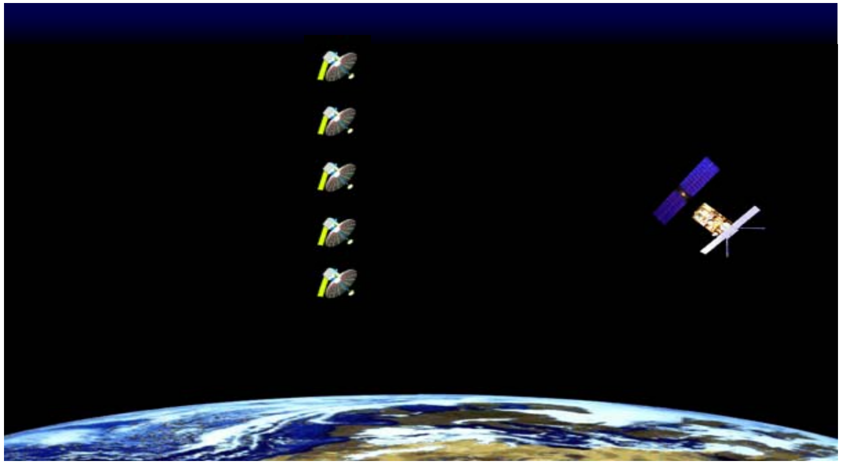


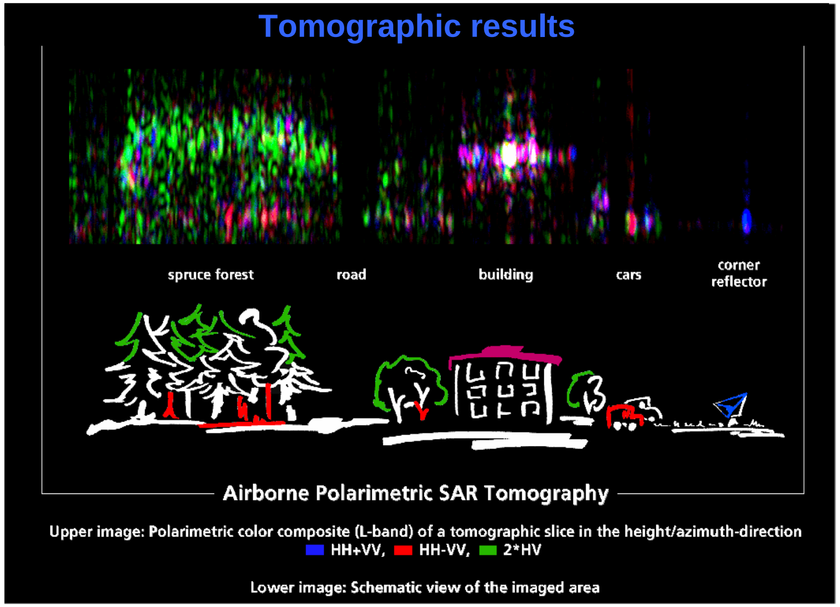
→ *Good Inversion Accuracy*

Tomography with Micro-Satellite Array

Basic Idea: Cluster of receiver satellites forming a sparse aperture in cross-track

- enables real three-dimensional imaging
- allows accurate measurement of vertical scatterer distribution
- reliable extraction of biophysical parameters (e.g. forest height, ground topography, ...)
- does not rely on a priori model assumptions
- not affected by layover or foreshortening
- cross-track distance between the individual satellites defines the height of ambiguity
- total tomographic baseline defines the height resolution

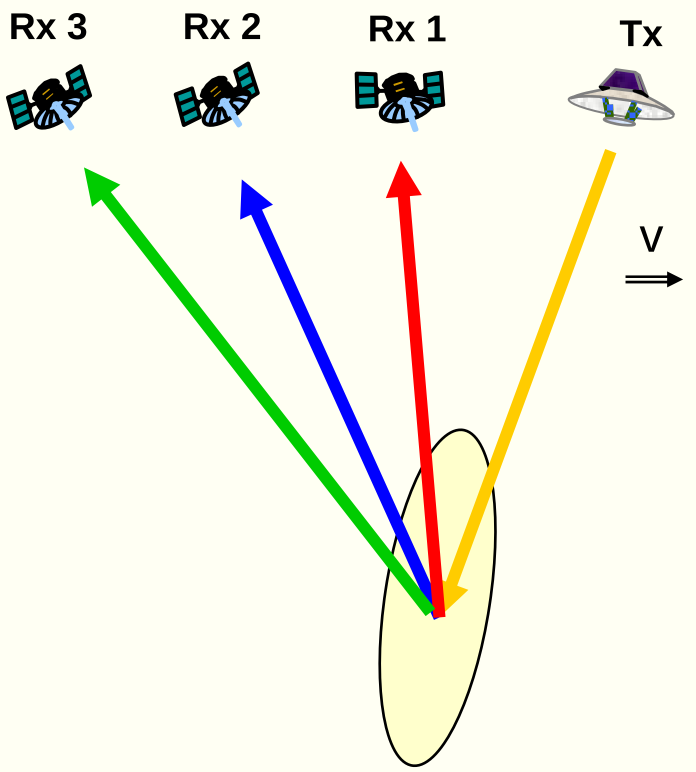




(from A. Reigber & A. Moreira, 2000)

Ambiguity Reduction and Wide Swath Imaging with Multiple Receivers

Distributed aperture radar with multiple receivers



- single transmitter illuminates ***wide image swath***
- multiple receivers record scattered signal simultaneously
- N receivers allow ***reduction of PRF*** by a factor of 1/N ***without*** raising ***azimuth ambiguities***:
  - increase of swath width by factor N at ***full azimuth resolution*** (as opposed to ScanSAR)
  - great variability in optimum receiver displacement:

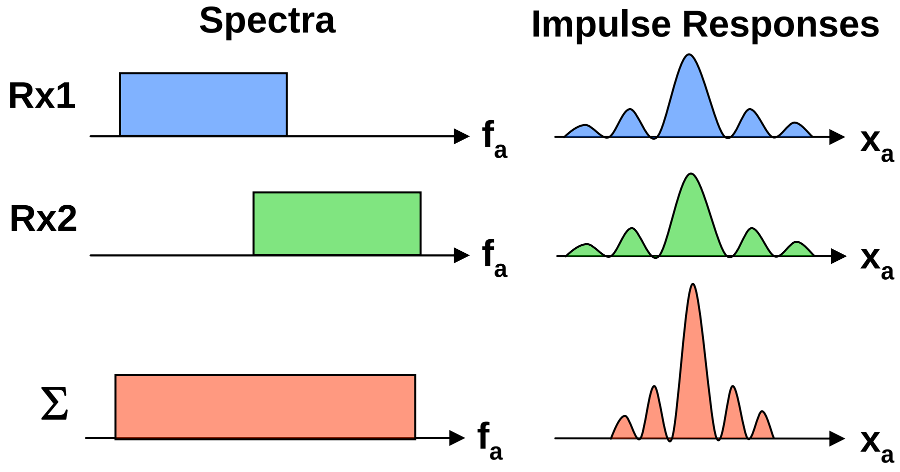
$$x_i - x_1 \approx \frac{2\cdot v}{PRF}\left(\frac{i\text{-}1}{N}+k_i\right) \quad i\in\{1,2,\ldots,N-1\}, k_i \in Z$$

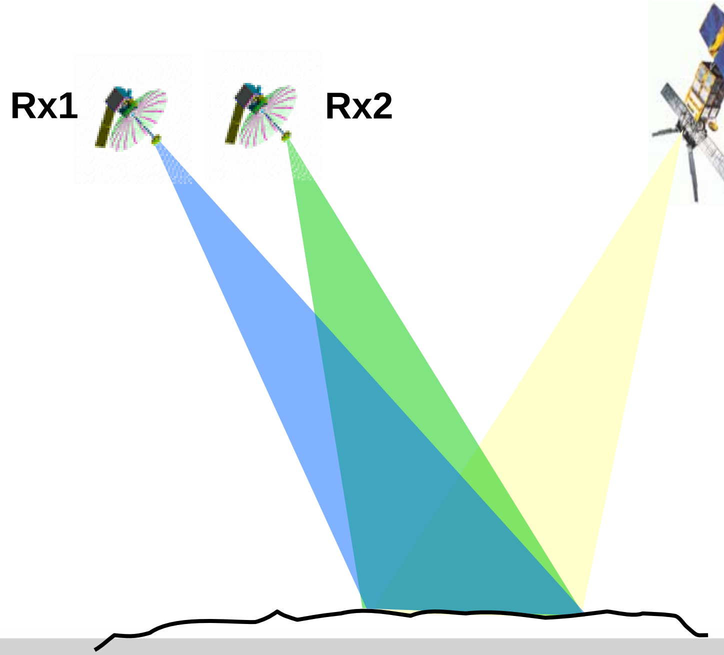
  - reconstruction also possible for other displacements
  - performance can be optimized by PRF adaptation
  - requires stable oscillators or RF synchronization and accurate measurement of relative displacement
- major application: ***high resolution*** imaging of a ***wide image swath*** with ***small antennas*** (e.g. distributed L-Band SAR with multiple microsatellites)

Super-Resolution with Passive Receivers

Increased geometric resolution of SAR images by:

- along-track displacement of parasitic satellites :
  - ⇒ different Doppler centroids
  - ⇒ super-resolution in azimuth by coherent combination of shifted Doppler spectra
- across-track displacement of receiving satellites:
  - ⇒ different incidence angles
  - ⇒ super-resolution in range by coherent combination of images with different ground range spectra

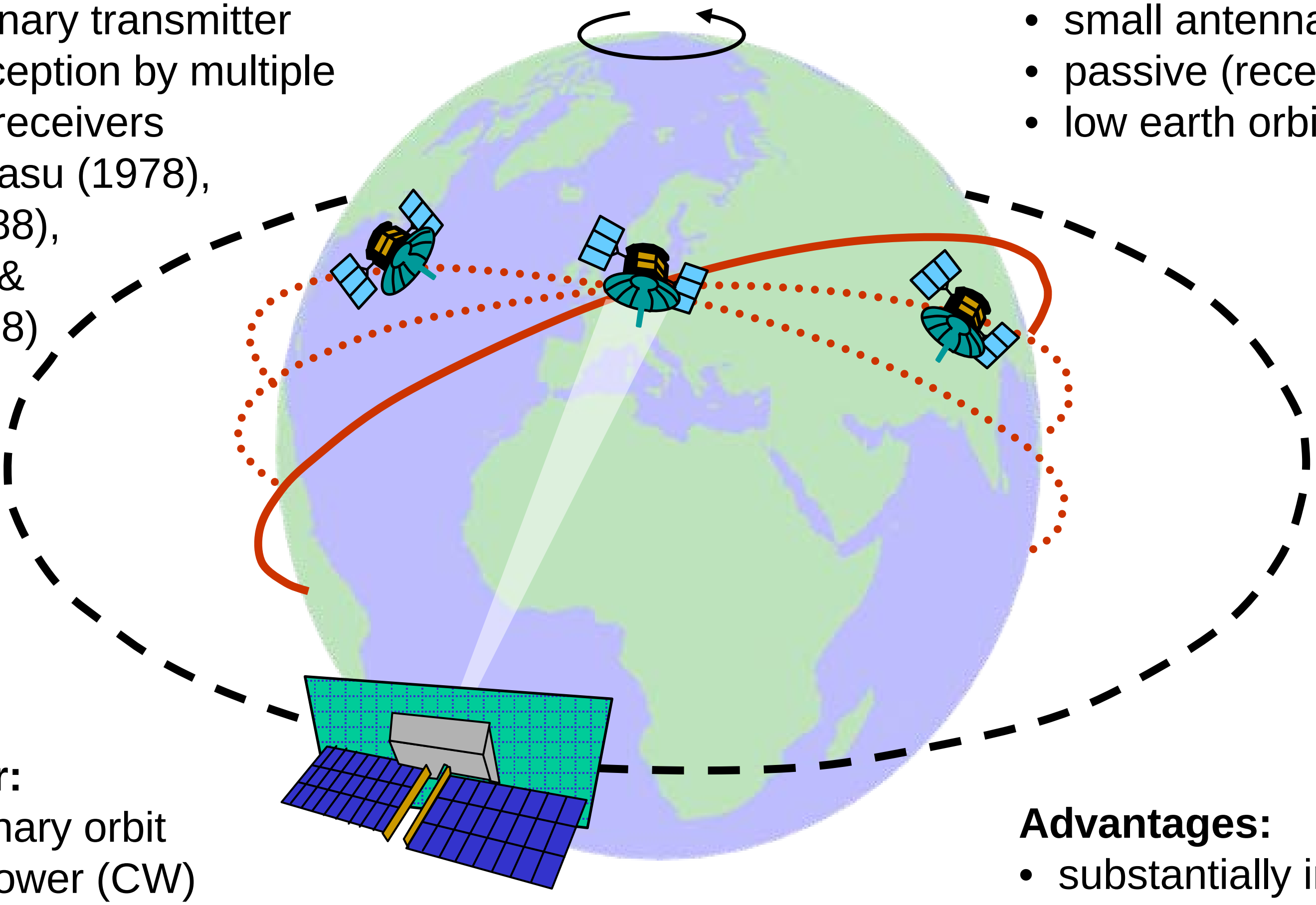




Geostationary Illuminator / LEO Receivers

Basic Idea:
- constant illumination by geostationary transmitter
- signal reception by multiple low-cost receivers
- cf. Tomiyasu (1978), Hartl (1988), Hounam & Zink (1998)

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

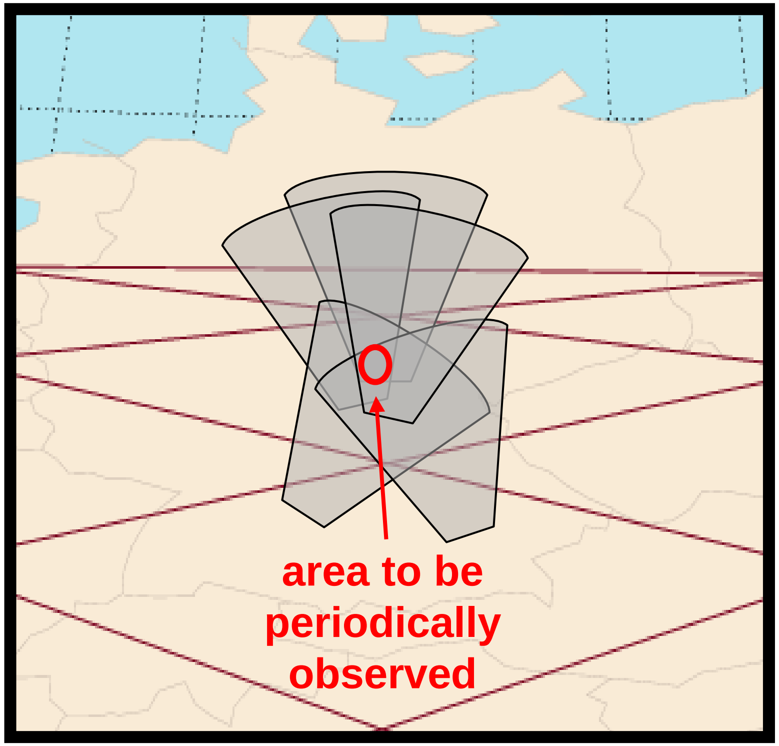


Illuminator:
- geostationary orbit
- high Tx power (CW)
- large antenna area
- optional: steerable antenna

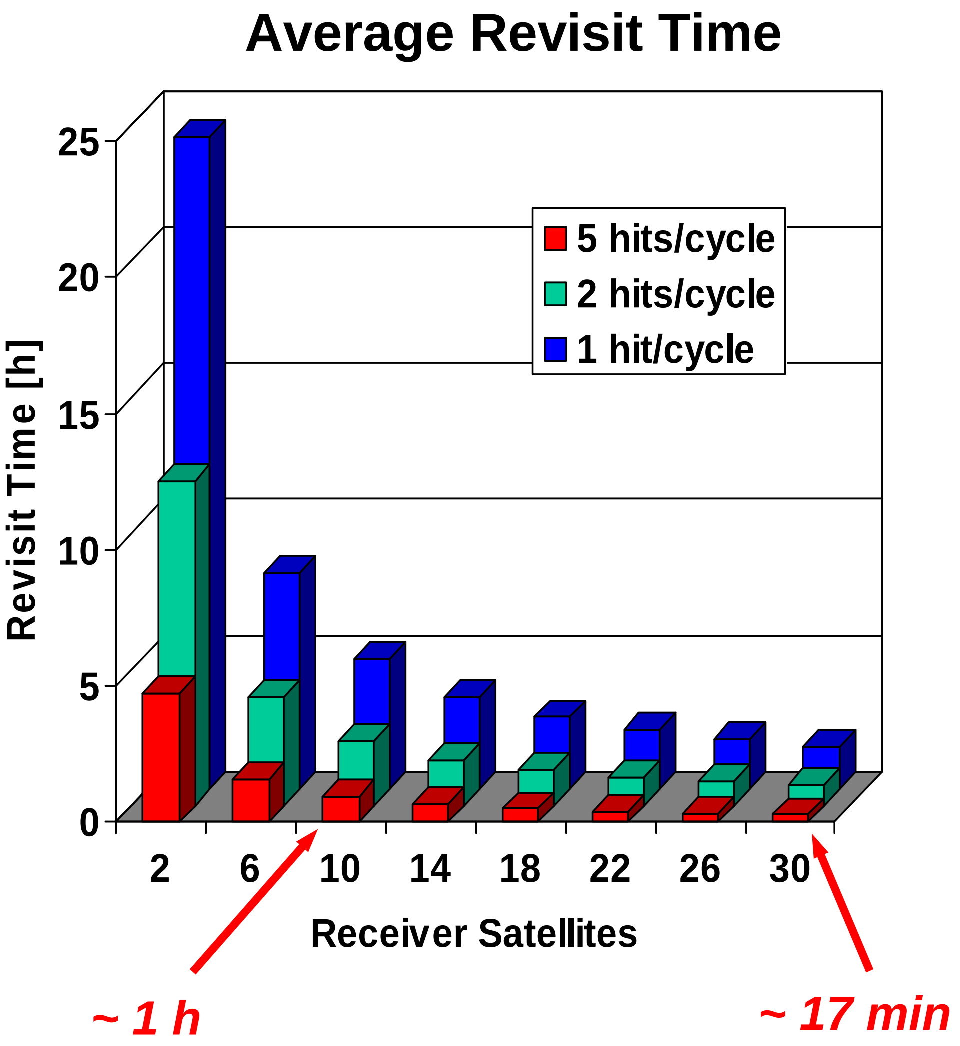
Advantages:
- substantially improved revisit times without cost explosion
- multiple missions may share one illuminator

LEO Receivers: Revisit Times

Example: *Orbit optimized for short revisit times of dedicated area (h=404 km, 31orbits/2days)*



⇒ up to 5 observations per repeat cycle



Digital Beamforming in Passive Receivers

Digital beamforming on receive makes effective use of the total signal energy in the large illuminated footprint:

⇒ ***mapping of a wide swath or multiple spots***
(in spite of extended antennas in elevation)

⇒ ***very long synthetic apertures***
(also with long receiver apertures)

– ***high azimuth resolution***

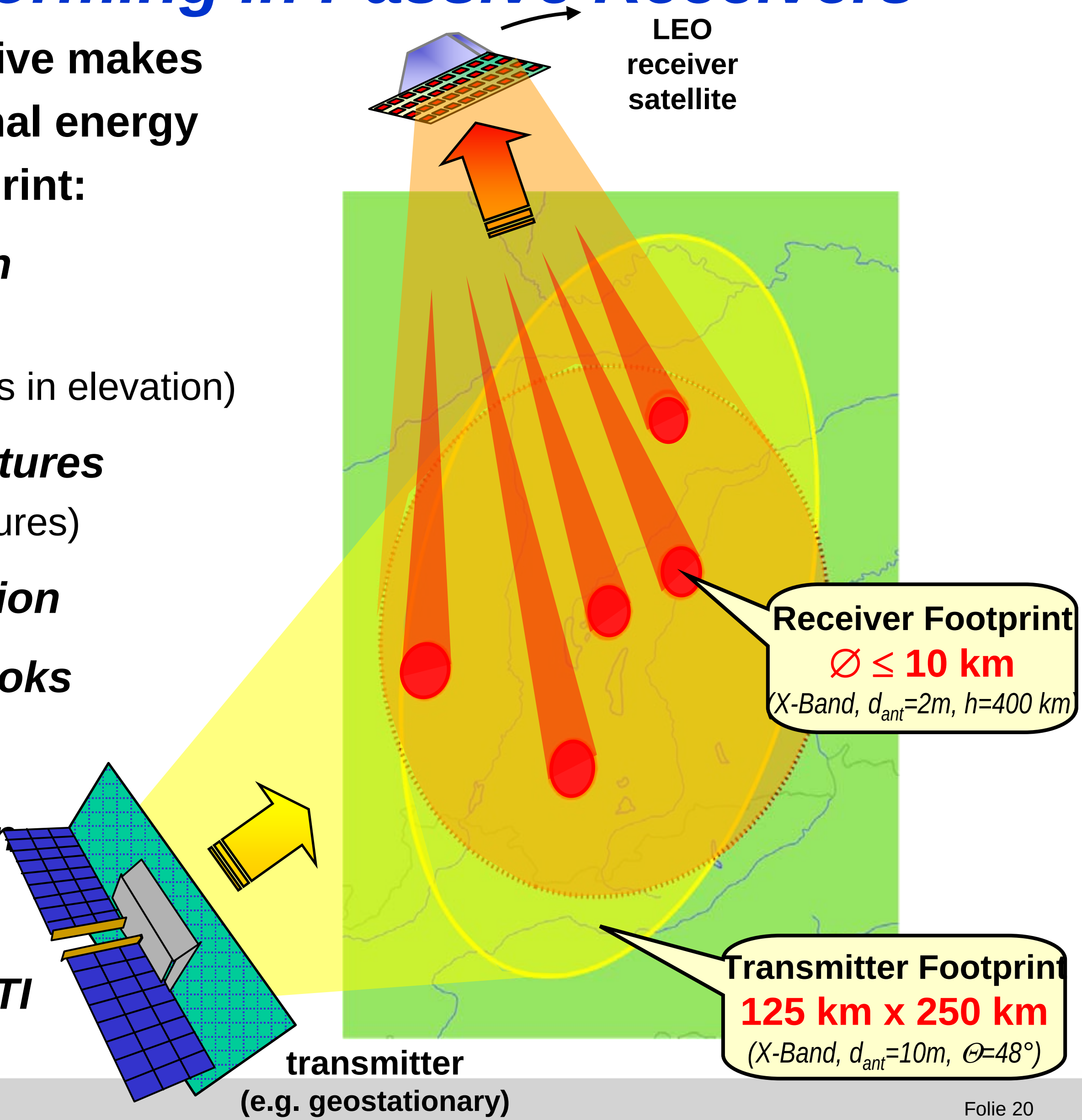
– ***more independent looks***

– ***improved sensitivity***

⇒ ***interference suppression***

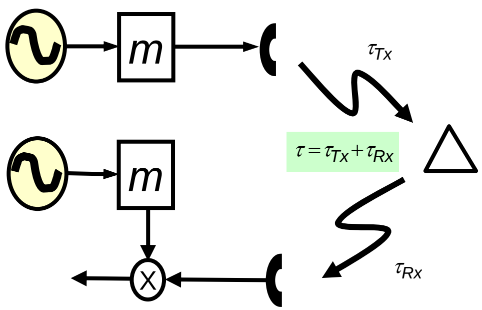
⇒ ***ambiguity reduction***

⇒ ***multiple phase center MTI (e.g. STAP)***

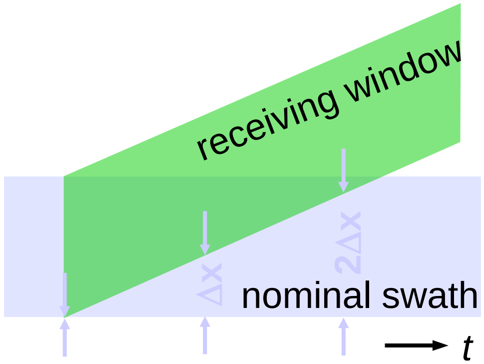


Challenges in Bi- and Multistatic SAR

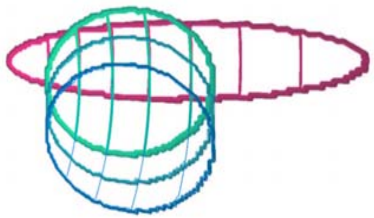
Oscillator Phase Noise



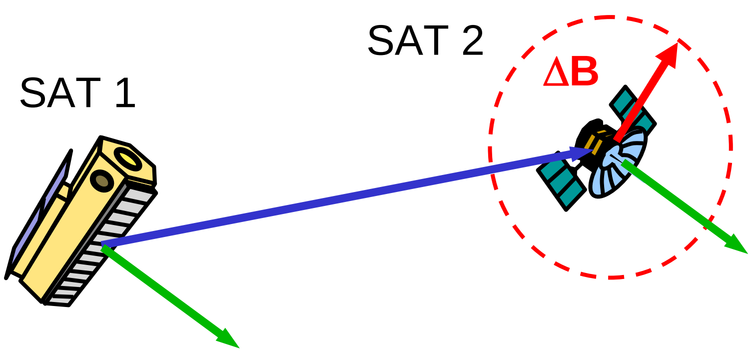
Pulse Synchronization



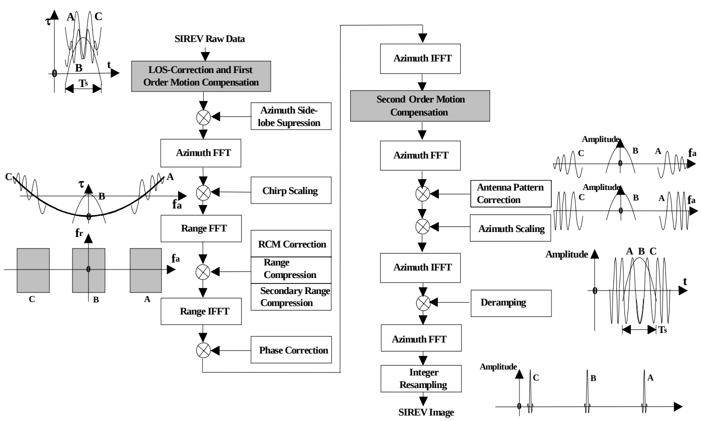
Antenna Pointing & Calibration



Orbit Control & Relative Position Sensing



Bistatic Processing



Conclusions

Future SAR systems must provide

- broad coverage and short revisit times
- multiple view angles, polarisations, baselines, and frequencies

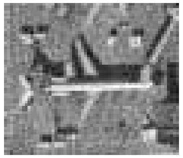
New and affordable concepts are

- 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

Vision


Corbis


Continuous Global Monitoring
for Environment and Security
by a Reconfigurable SAR
Satellite Constellation




Corbis

Questions