GMES Sentinel-1 System Overview

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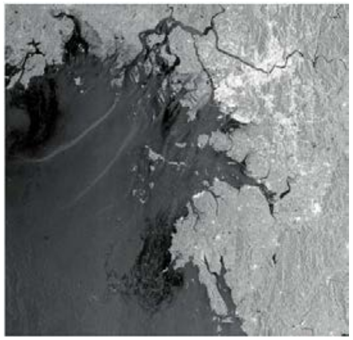
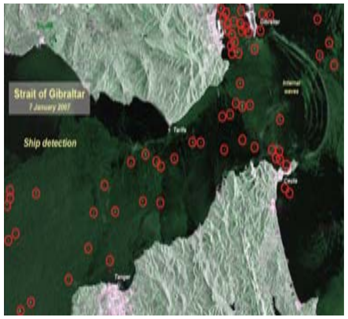
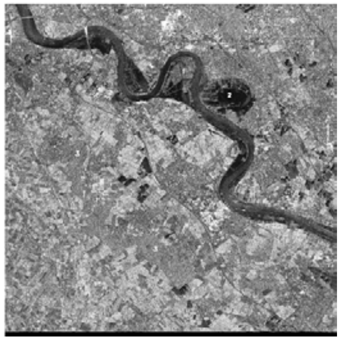
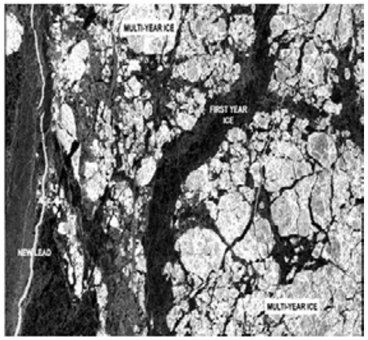
Sentinel-1 Mission Objectives and Requirements (1/2)

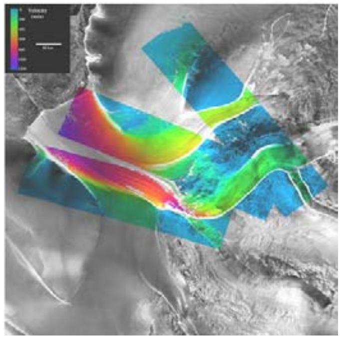
- Provide routinely and systematically SAR data to *GMES services* and *National services* focussing on the following applications
  - ✓ Monitoring of marine environment (e.g. oil spills, sea ice zones)
  - ✓ Surveillance of maritime transport zones (e.g. European and North Atlantic zones)
  - ✓ Land Monitoring (e.g. land cover, surface deformation risk)
  - ✓ Mapping in support of crisis situations (e.g. natural disasters and humanitarian aid)
  - ✓ Monitoring of Polar environment (e.g. ice shelves and glaciers)

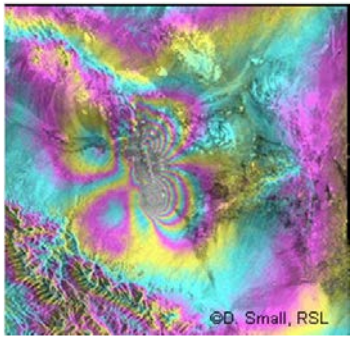




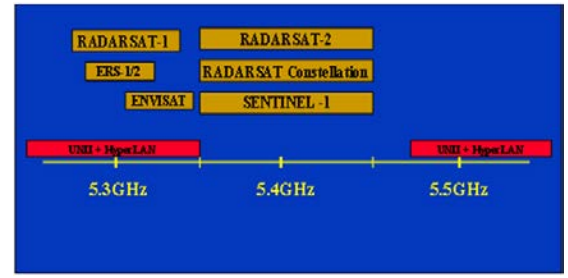




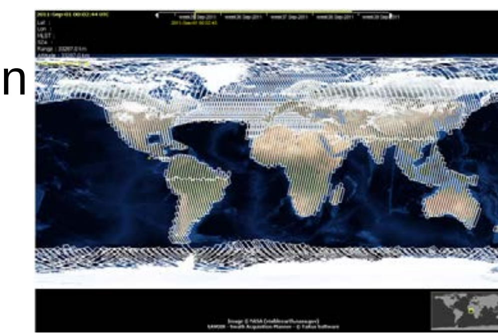




Sentinel-1 Mission Objectives and Requirements (2/2)

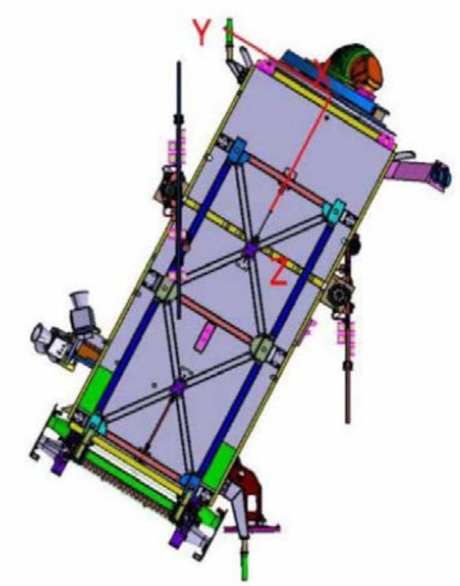


- Provide C-band SAR data continuity (at 5.405 GHz)
- Data quality similar or better than ERS/ENVISAT (e.g. equalized performance across the swath)
- Complete global coverage within a single repeat orbit cycle (175 orbits in 12 days) and systematic revisit (greatly improved as compared to ENVISAT)
- Capability for repeat-pass SCANSAR interferometry (i.e.TOPS InSAR)
- Systematic data acquisition to enable build-up of long observation time series
- High system availability (i.e. SAR duty cycle)
- Conflict-free operations w.r.t. SAR mode selection for data acquisition (swath width and polarization)
- On-board data latency (i.e. downlink) requires:
  - max 200 min (2 orbits)
  - One orbit for support of near real time (3h) applications
  - Simultaneous SAR acquisition and data downlink for real time applications



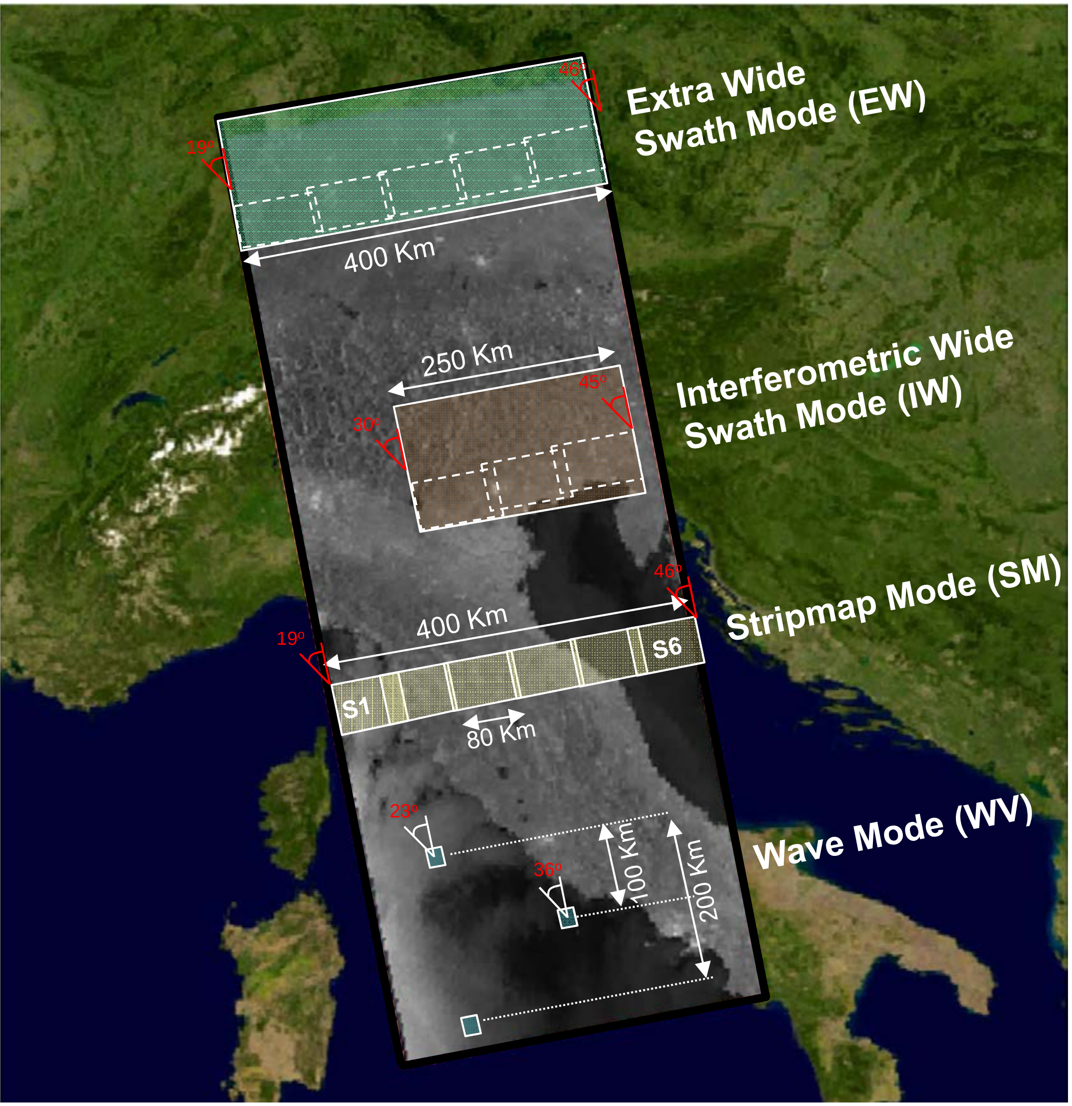
Sentinel–1 Mission Facts

- Constellation of two satellites (A & B units)
- C-Band Synthetic Aperture Radar Payload (at 5.405 GHz)
- 7 years design life time with consumables for 12 years
- Near-Polar sun-synchronous (dawn-dusk) orbit at 698 km
- 12 days repeat cycle (1 satellite), 6 days for the constellation
- Both S-1 satellites are in the same orbital plane (180 deg. phased in orbit)
- On-board data storage capacity (mass memory) of 1400 Gbit
- Two X-band RF channels for data downlink with 2 X 260 Mbps
- On-board data compression using Flexible Dynamic Block Adaptive Quantization (FDBAQ)
- Optical Communication Payload (OCP) for data transfer via laser link with the GEO European Data Relay Satellite (EDRS)
- Launch of Sentinel-1 A scheduled for October 2013 followed by Sentinel-1 B 18 months later



Sentinel-1 SAR Imaging Modes (1/2)

- Instrument provides *4 exclusive SAR modes* with different resolution and coverage



- **Polarisation schemes** for IW, EW & SM:
  - ✓ single pol: HH or VV
  - ✓ dual pol: HH+HV or VV+VH
- Wave mode: HH or VV
- **SAR duty cycle per orbit**:
  - ✓ up to *25 min* in any of the imaging modes
  - ✓ up to *74 min* in Wave mode

Main mode of operations: *IW* designed to satisfy most GMES user/service requirements (i.e. resolution, swath width, polarisation)

***WV* mode** is continuously operated over open ocean

Sentinel-1 SAR Imaging Modes (2/2)

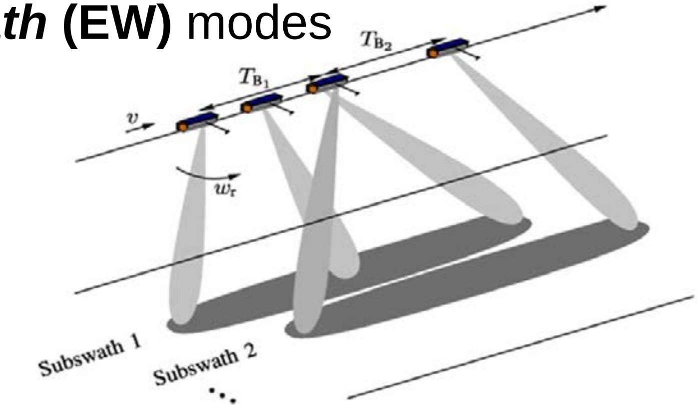
Mode	Incidence Angle	Single Look Resolution	Swath Width	Polarisation	Chirp bandwidth [MHz]
Interferometric Wide Swath (IW 1-3)	30-42 deg.	Range 5 m Azimuth 20 m	250 km	HH+HV or VV+VH	56.50 – 42.80
Wave mode WV1 WV2	23 deg. 36.5 deg.	Range 5 m Azimuth 5 m	20 x 20 km Vignettes at 100 km intervals	HH or VV	74.5 48.2
Strip Map S1-S6	20-43 deg.	Range 5 m Azimuth 5 m	80 km	HH+HV or VV+VH	87.60 – 42.20
Extra Wide Swath (EW 1-5)	20-44 deg.	Range 20 m Azimuth 40 m	400 km	HH+HV or VV+VH	22.20 – 10.40

Image Quality Parameters for all Modes (worst case)

Radiometric Accuracy (3σ)	**1 dB**
Noise Equivalent Sigma Zero	**-22 dB**
Point/Distributed Target Ambiguity Ratio	**-25/ -22 dB**
Phase Error over 10 min	**5 deg**

Sentinel-1 SAR TOPS Mode

TOPS (Terrain Observation with Progressive Scans in azimuth) for Sentinel-1 ***Interferometric Wide Swath (IW)*** and ***Extended Wide Swath*** **(EW)** modes



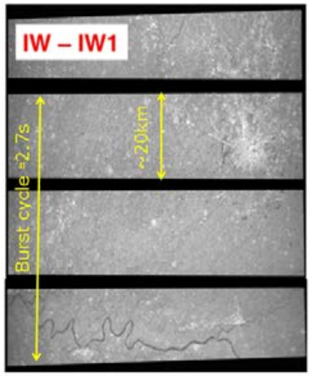
- Provides large swath width (ScanSAR) & and enhanced radiometric performance due to reduced scalloping effect
- Important because there is only *1 azimuth look* available

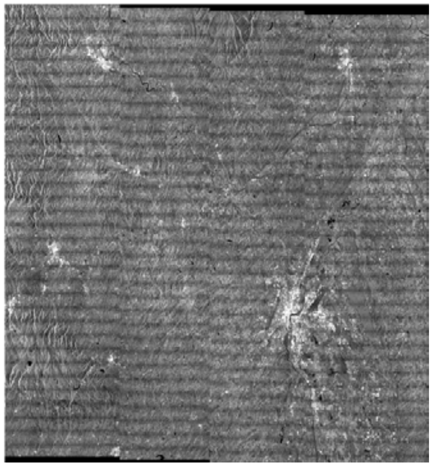
⇒ radiometric look balancing is not possible (e.g. ENVISAT)

TOPS Mode implementation: ScanSAR + azimuth Scan:

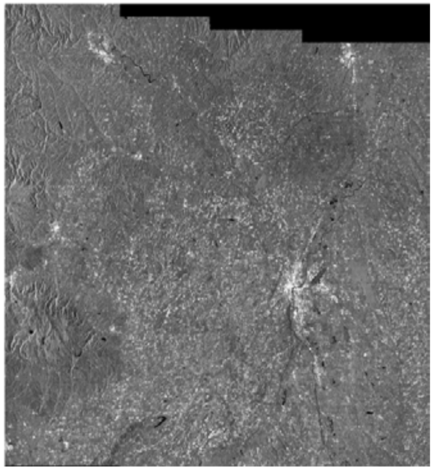
±0.8° azimuth scanning at PRI rate

±12° elevation scanning and beam shaping capability

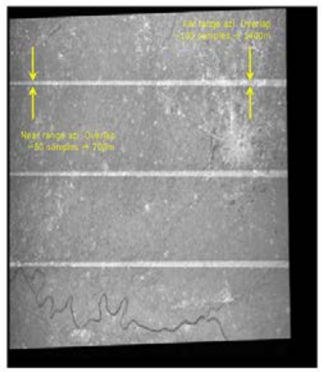




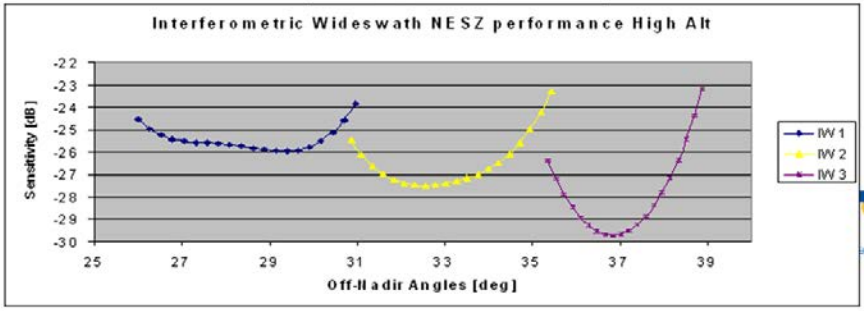
TSX-ScanSAR image



TSX-TOPS image

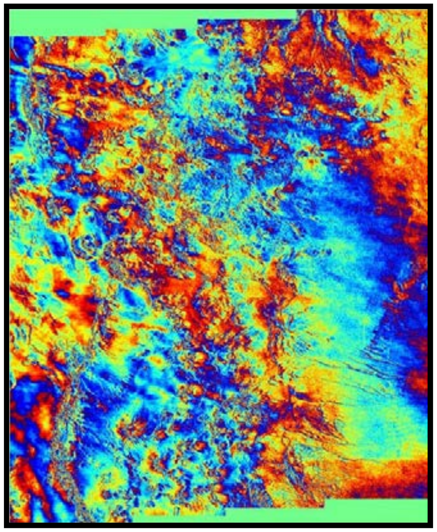


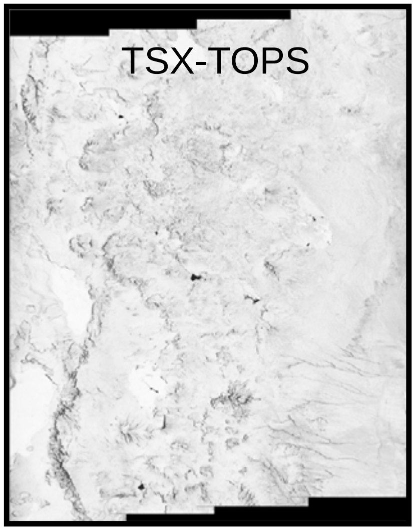
Interferometric Wideswath

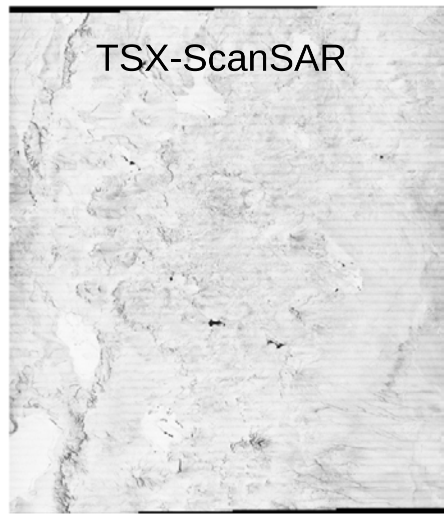


Sentinel-1 TOPS InSAR Capability (1/2)

- S-1 TOPS InSAR study based on TerraSAR-X TOPS data, e.g. acquired over Atacama desert (Chile) having 11-day repeat pass interval



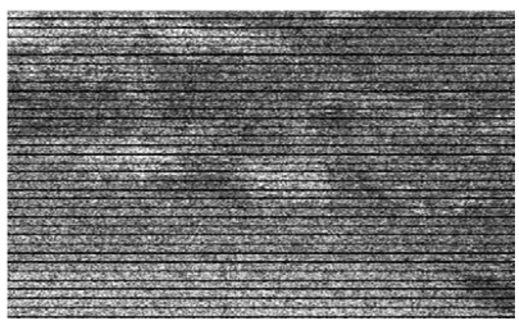


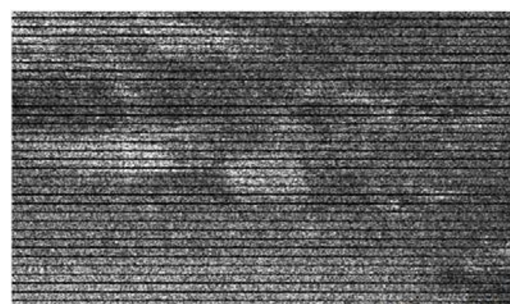


- Coherence loss in ScanSAR due to SNR degradation at burst edges (after azimuth pattern correction)

Image courtesy: P. Prats, DLR

- TOPS interferogram generation requires burst synchronization of repeat-pass datatakes
- TOPS burst duration for:
  - ✓ EW: 0.54 s (worst case)
  - ✓ IW : 0.82 s (worst case)
- Requirement for Burst Synchronization: ≤ 5ms





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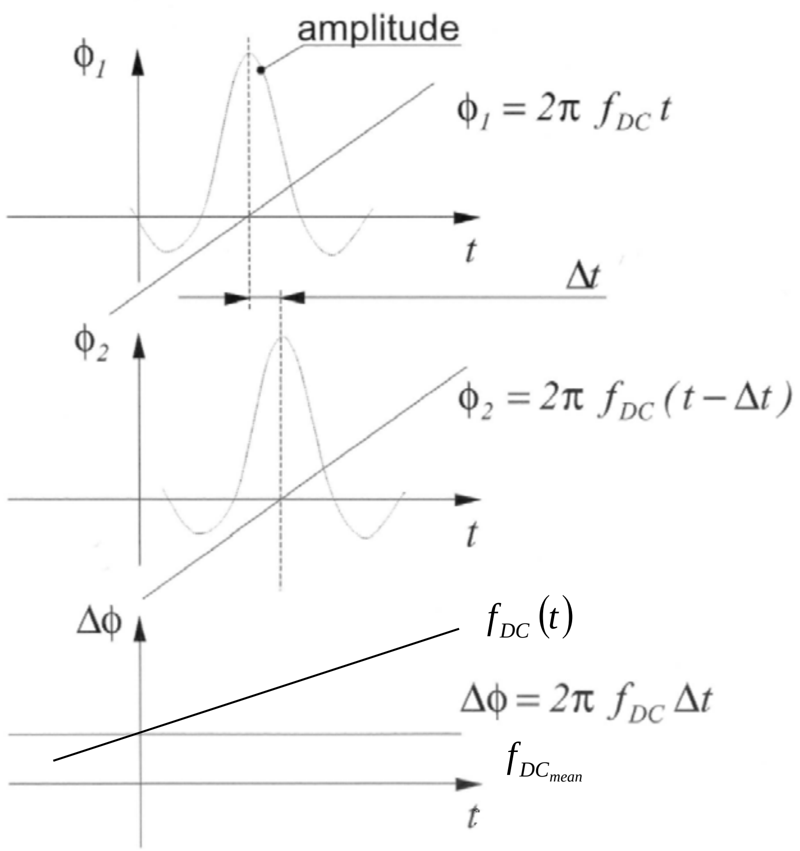
Sentinel-1 TOPS InSAR Capability (2/2)

- Azimuth antenna sweeping causes Doppler centroid variations of about 5.5 kHz within bursts
  - Introduces an azimuth phase ramp (azimuth fringes) for small co-registration errors

$$\phi_{az_{err}} = 2\pi\, f_{DC}\, \Delta t$$



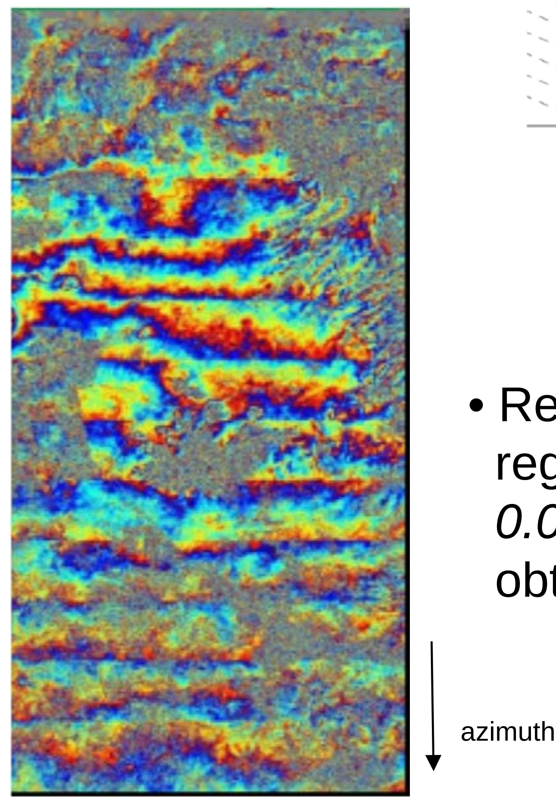
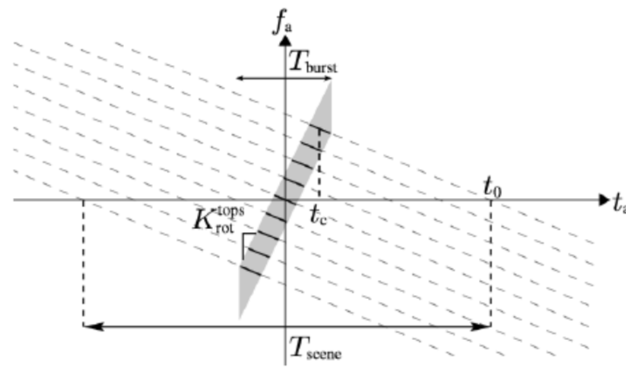


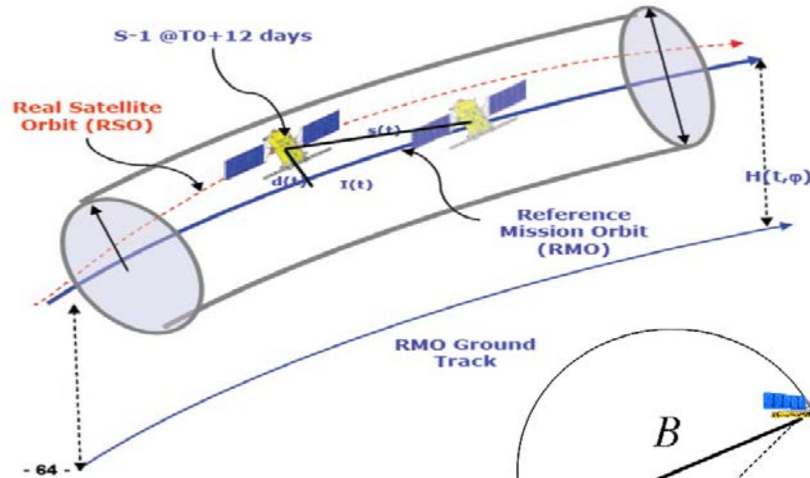
Image courtesy: P. Prats, DLR

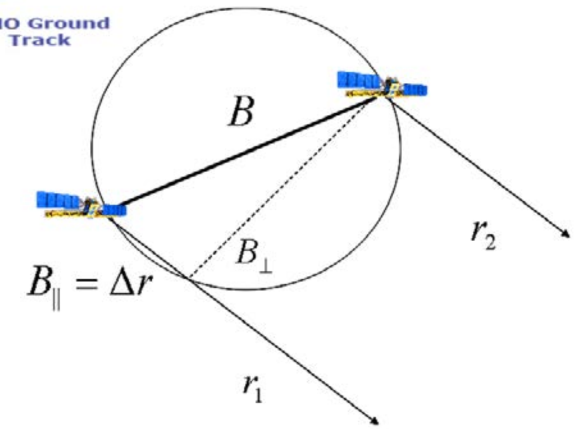


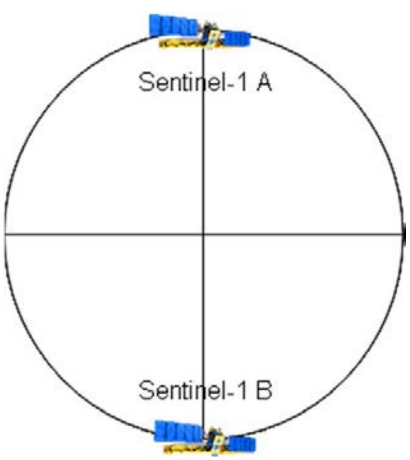
- Requires azimuth co-registration to be better than *0.001 samples* in order to obtain phase error less than 3°

Sentinel-1 Orbital Tube and InSAR Baseline

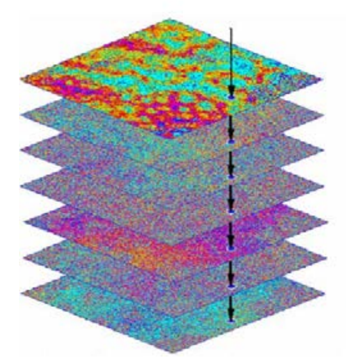
- Satellite will be kept within an *Orbital Tube* around a Reference Mission Orbit (RMO)
- *Orbital Tube* radius (statistical) is 50 m (rms)
- Orbit control is achieved by applying *across-track dead-band* control at the most *Northern point* and *Ascending Note* crossing







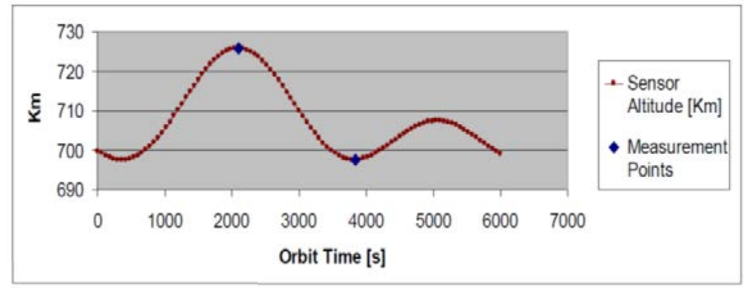
- Sentinel-1 A & B will fly in the same orbital plane with *180 deg.* phased in orbit
- *12-day repeat* orbit cycle for each satellite
- Formation of SAR interferometry (InSAR) data pairs having time intervals of *6-days*



Sentinel-1 Attitude Steering Modes

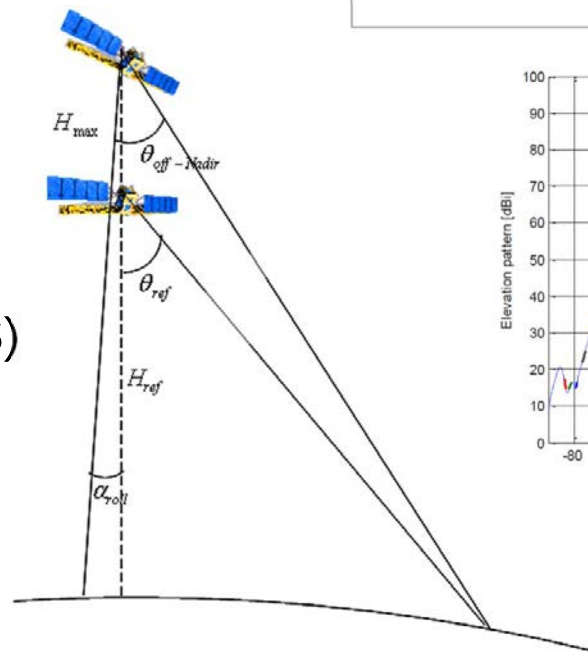
Roll-steering mode

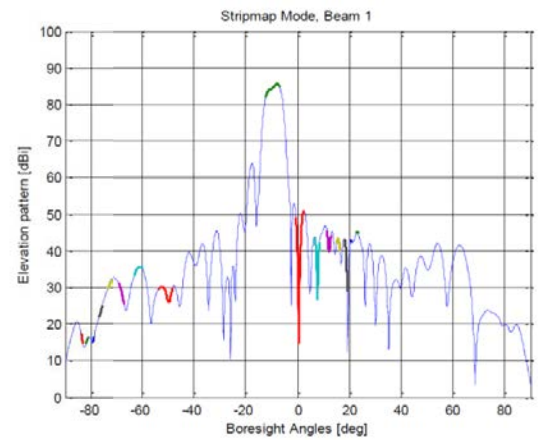
- Sensor altitude changes around the orbit
- Introduction of additional satellite *roll angle* depending on latitude to maintain a quasi "*constant*" *slant range*



at H_{min} = 697.6 km $\Rightarrow \theta_{off\text{-}Nadir}$ = 30.25°

at H_{max} = 725.8 km $\Rightarrow \theta_{off\text{-}Nadir}$ = 28.65°

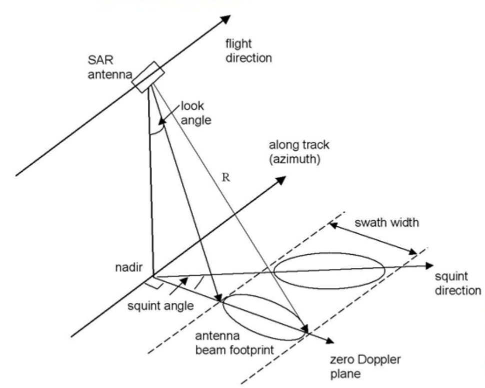




Advantages:

- *Single PRF* round orbit per swath or subswath (except for S5 (S5-N and S5-S)
- Fixed set of constant *Elevation antenna beam patterns*

Total zero-Doppler steering mode

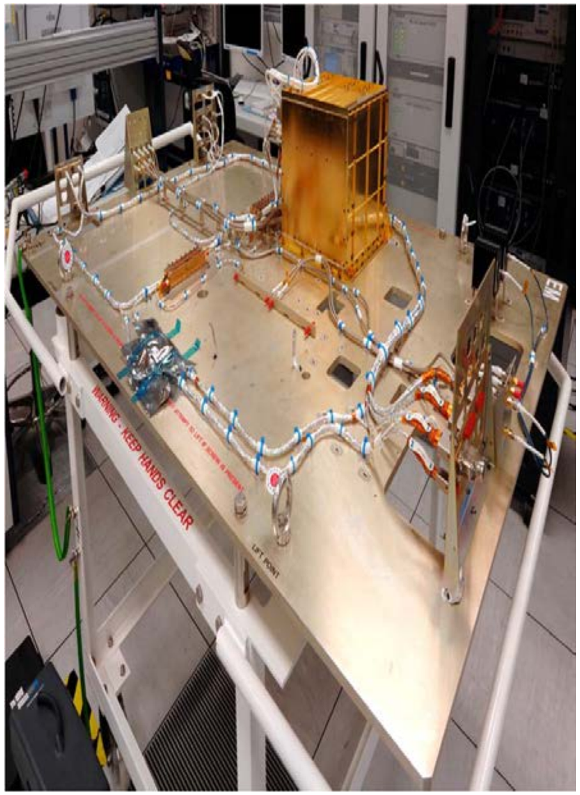


- Yaw and pitch adjustments around the orbit to account for Earth rotation effect
- Provides Doppler centroid at about 0 Hz

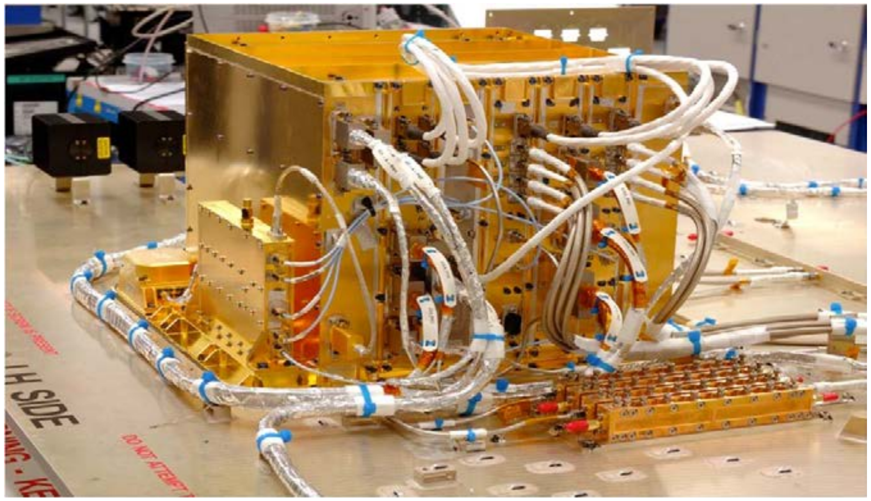
Sentinel-1 C-SAR Instrument

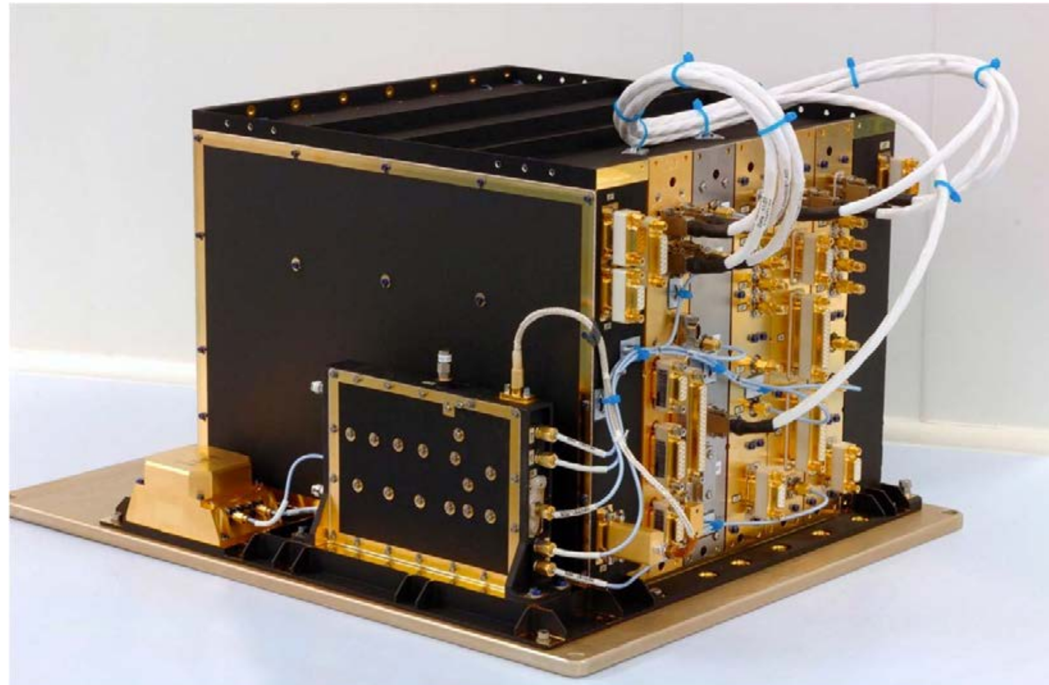
- SAR Electronics Subsystem (SES)
  - ENVISAT and RADARSAT-2 heritage
  - Real Sampling (digital I and Q demodulation)
  - High-efficient SAR data compression (FDBAQ)
  - Produces self-standing data packets

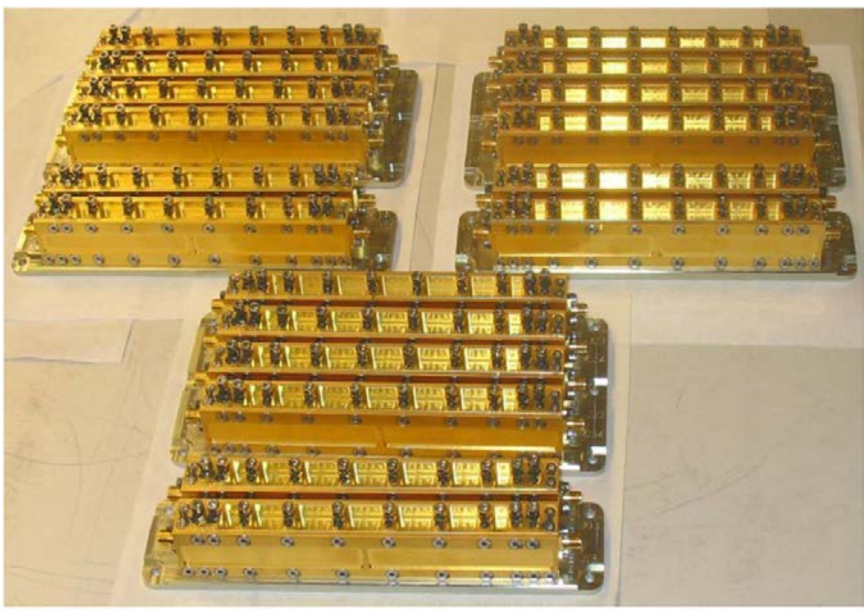
- SAR Antenna Subsystem (SAS)
- (12.3 x 0.84 m) with 14 tiles in 5 deployable panels
  - Plated CFRP Waveguides (low-loss) - TerraSAR-X heritage
  - T-compensated T/R modules - COSMO-SkyMed heritage
  - Internal calibration for Radiometry – ERS/ENVISAT heritage



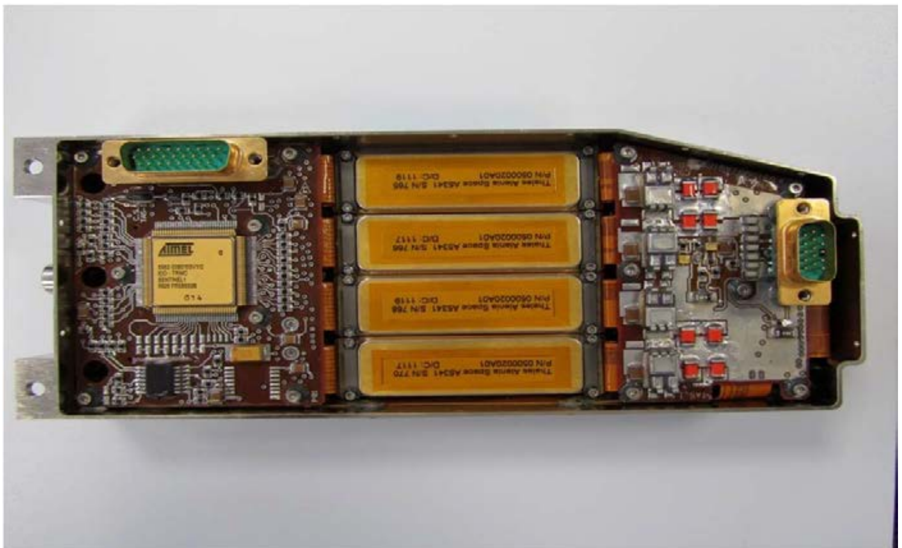
Sentinel-1 SAR Electronics Subsystem

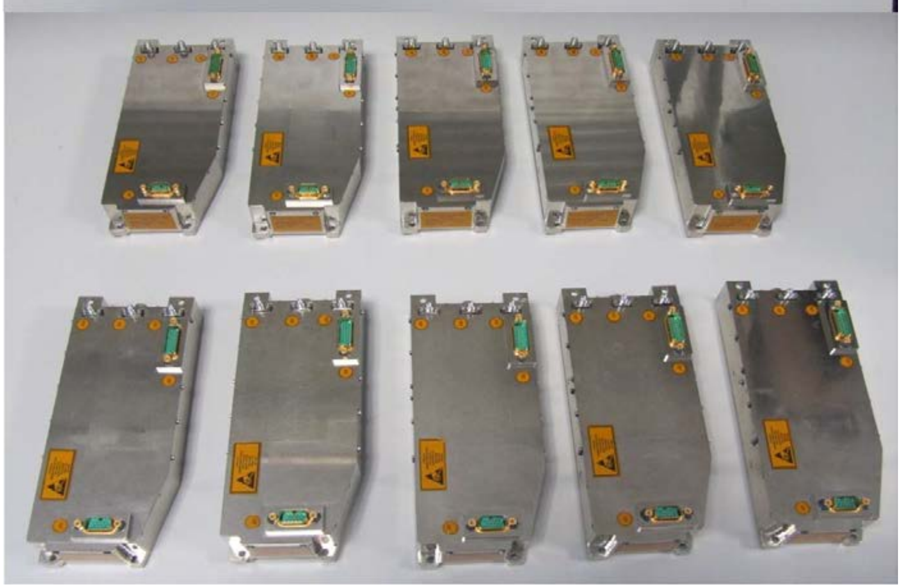


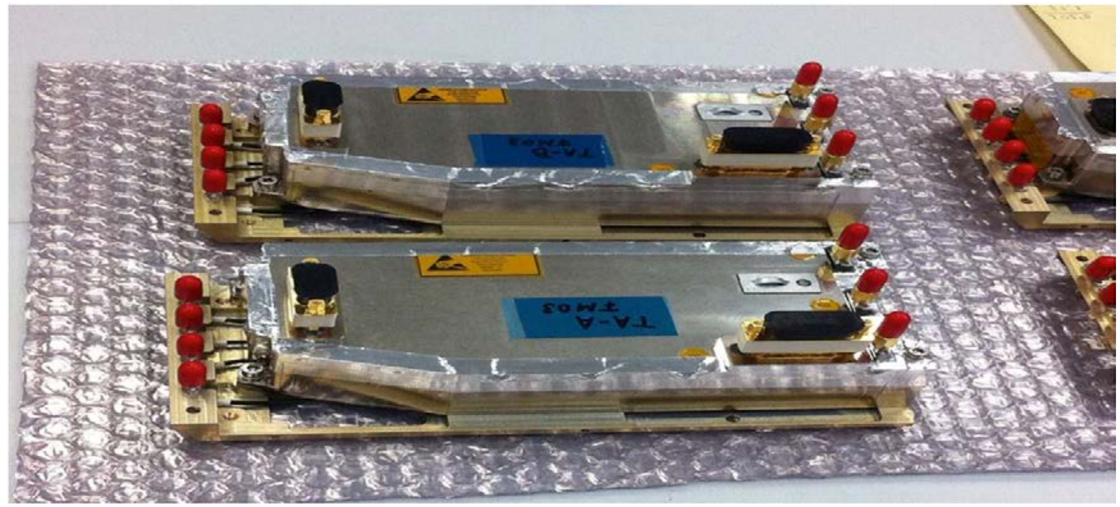


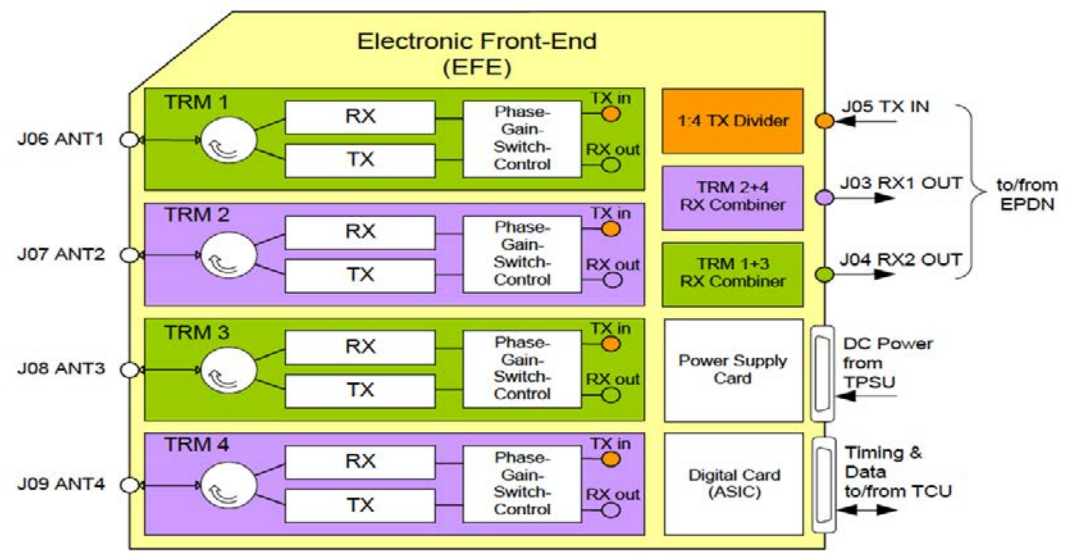


Transmit Receive Modules

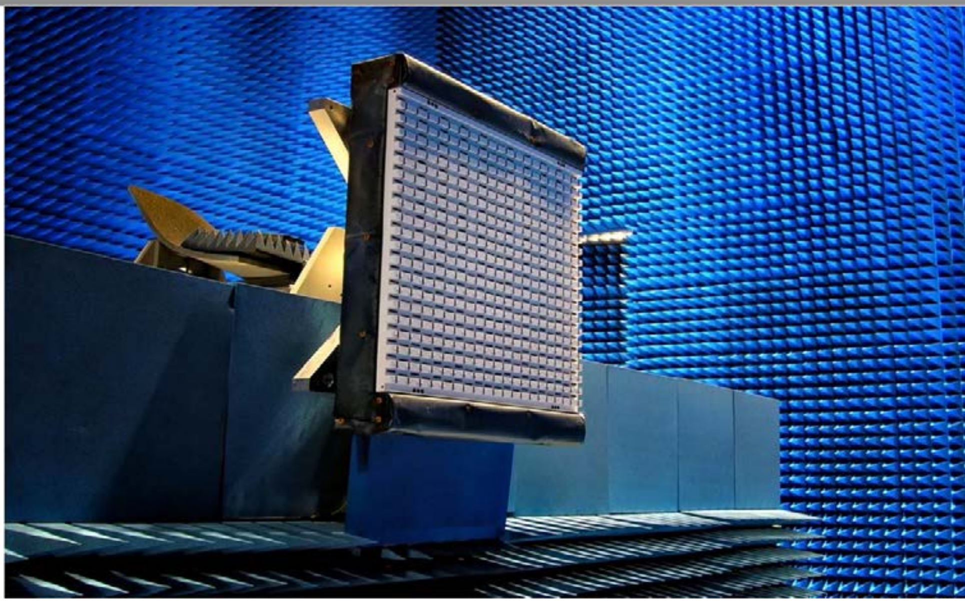


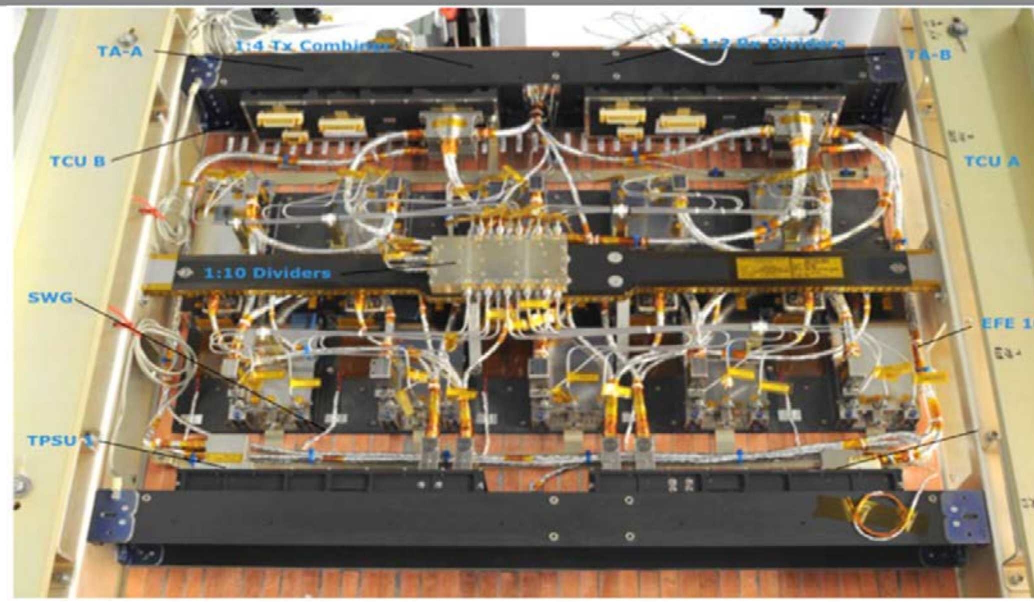


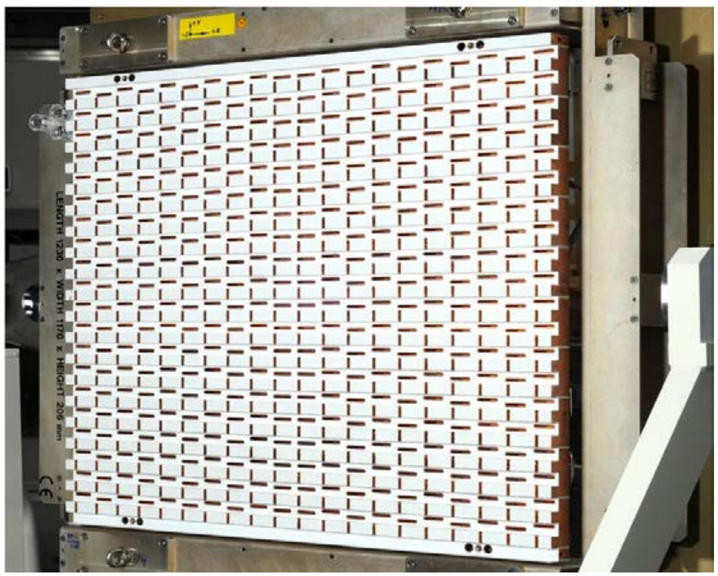


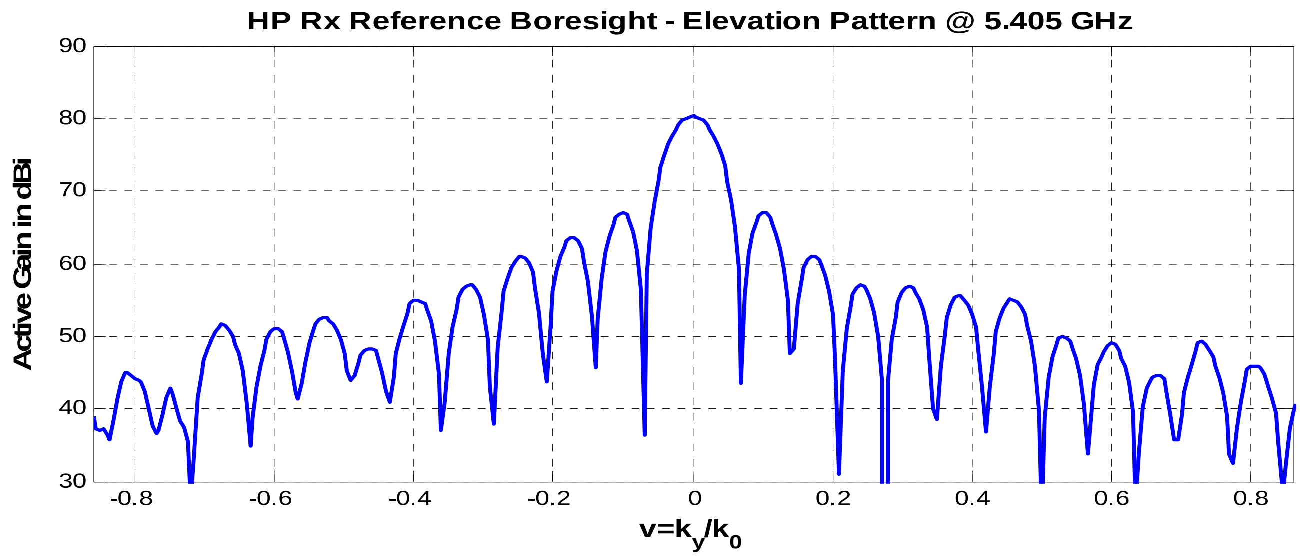


SAR Antenna Subsystem Tile

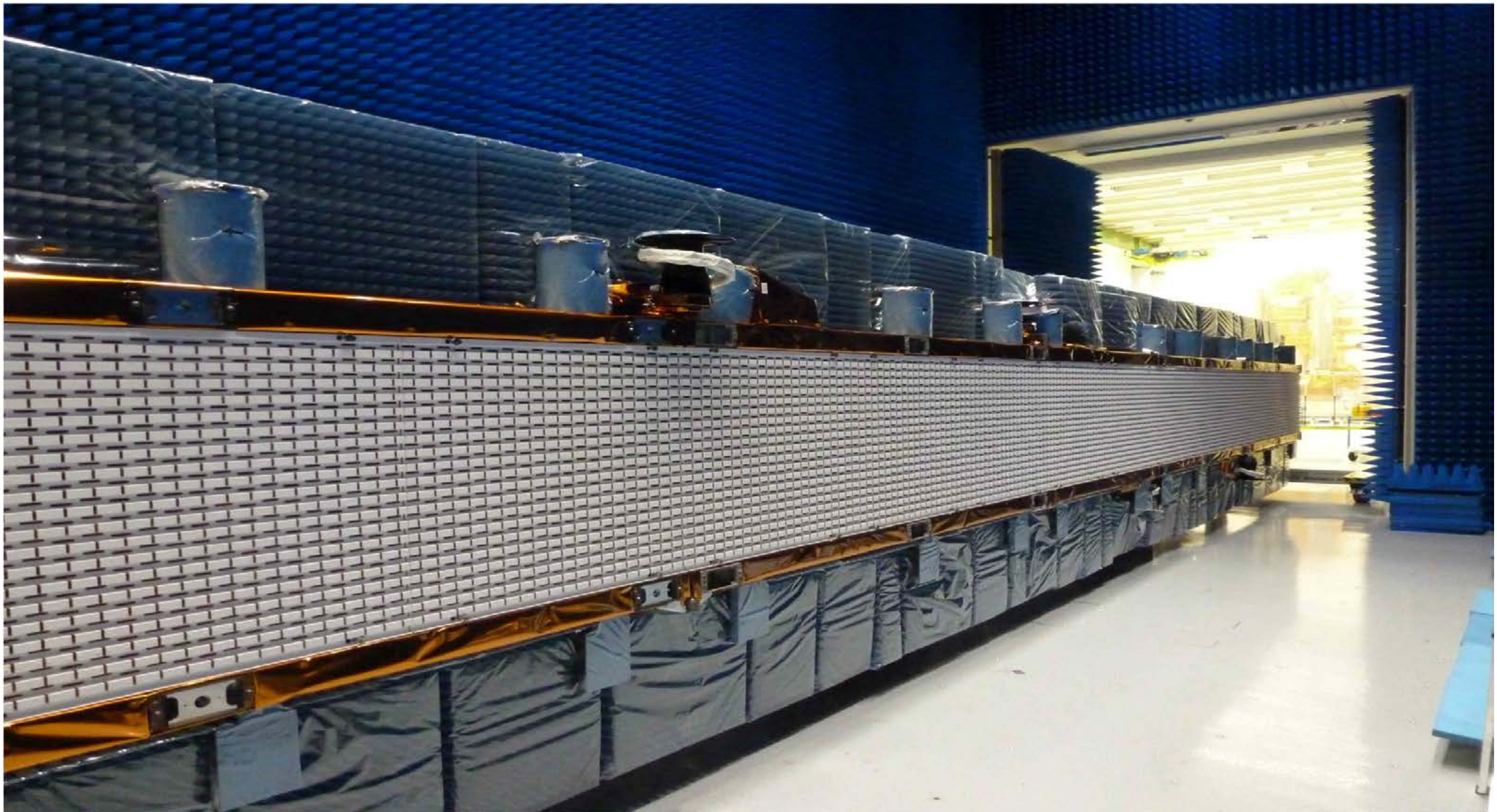








SAR Antenna Testing



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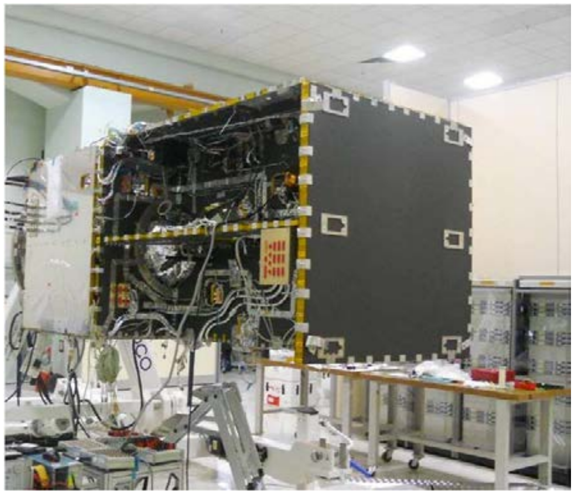
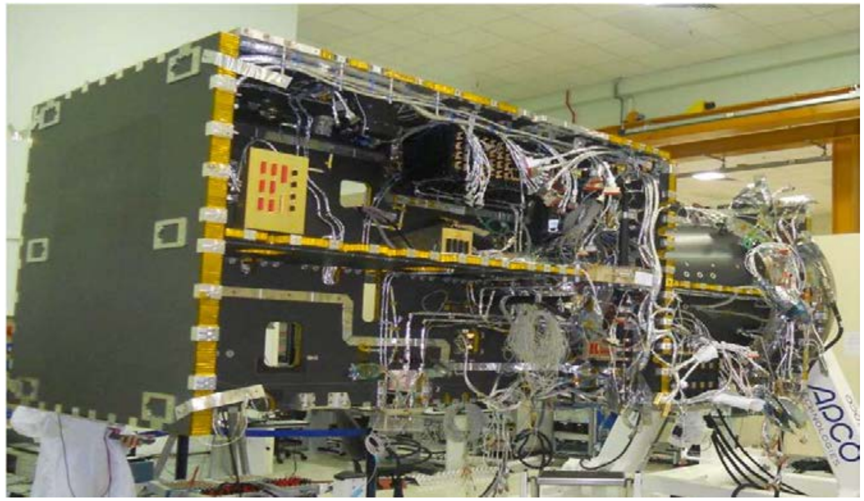
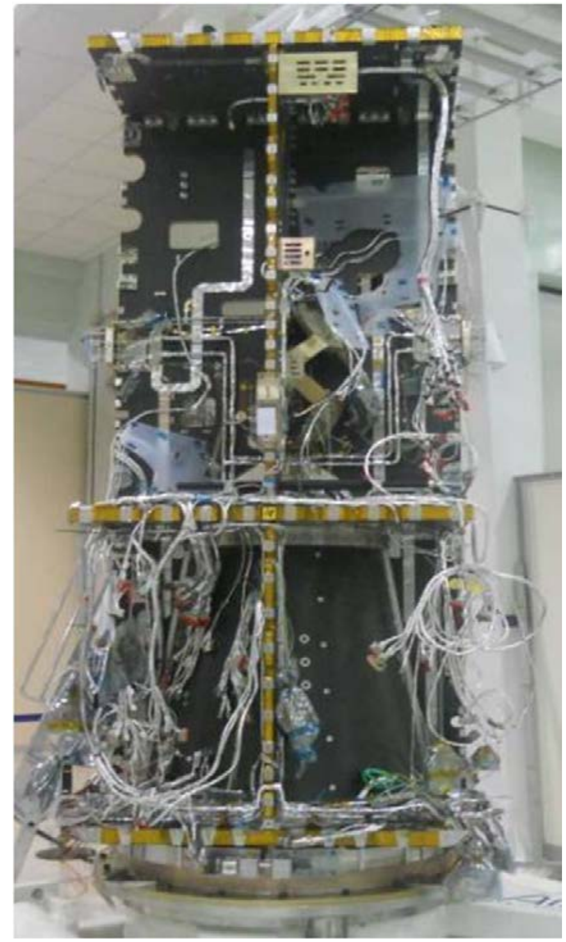
Sentinel-1 Platform







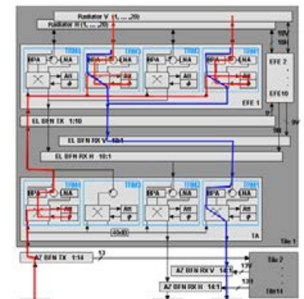
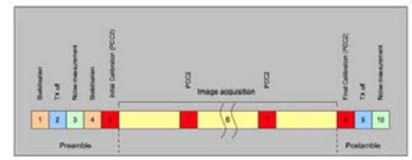
Central Structure with PCDU & CAPS Panels and with Propulsion S/S and Harness integrated

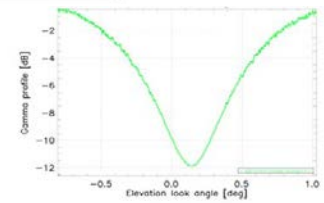
Solar Array deployment

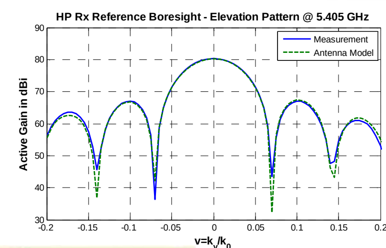
Sentinel-1 In-Orbit Commissioning Phase Activities

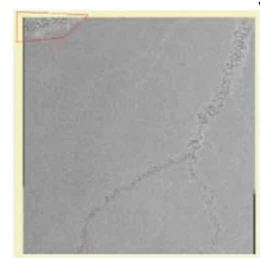
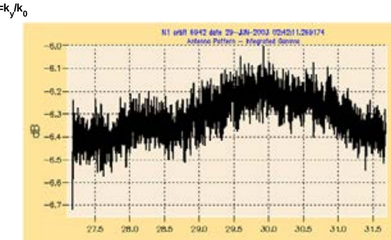
End-to-End Spacecraft and System performance verification and calibration

- Check-out of spacecraft and ground segment
- In-orbit verification of instrument performance and calibration:
  - ✓ internal instrument calibration using network of calibration pulses to monitor drift in Tx & Rx signal paths, and PCC techniques to monitor T/R modules
  - ✓ antenna pointing calibration (< 0.01°)
  - ✓ antenna model verification (0.2 dB (3σ) for absolute 2-way gain)
  - ✓ absolute radiometric calibration (< 1 dB (3σ))
  - ✓ radiometric stability (<0.5 dB (3σ))
  - ✓ geometric calibration (pixel localization: 2.5m (3σ))
  - ✓ polarimetric calibration
  - ✓ interferometric verification
- Level 0 and Level 1b SAR product verification (i.e. wrt SAR instrument performance)





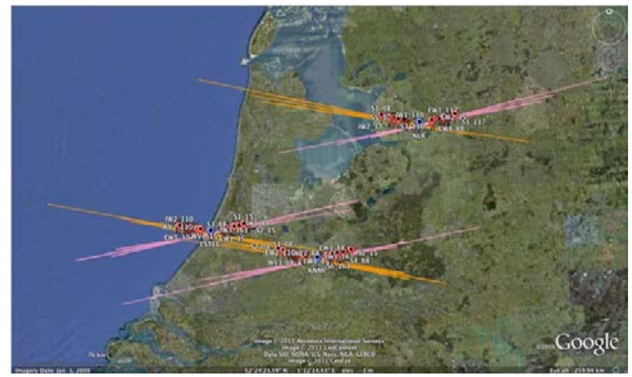




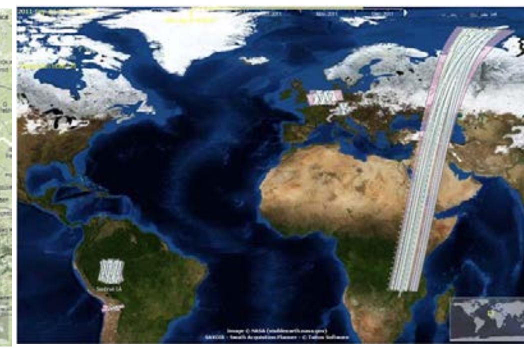
To be completed within *3 months* (Challenge!)

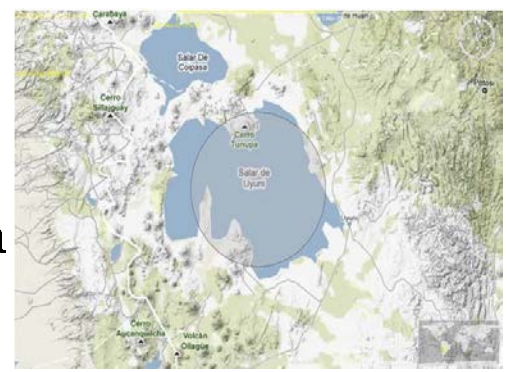
Sentinel-1 Commissioning Phase Calibration Sites

Current timeline consists of data acquisitions over:

- Transponder sites (3) in NL
- Lake and desert areas for NESZ measurement
- Rainforest for antenna model verification and radiometric calibration
- Long data takes (25 minutes) for all modes
- DLR test site for complementary calibration activities (Corner reflectors and transponders)
- InSAR verification sites (systematic generation repeat-pass interferograms (e.g. Lake Uyuni, Atacama desert, Death Valley)
- Measurement of InSAR phase stability (closed loop phase) over Corner Reflector site at DLR
- Measurement of phase stability in overlap area between bursts and sub-swaths







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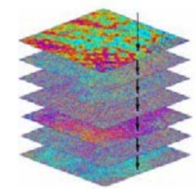
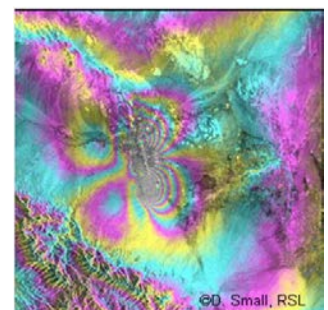
Conclusions

- Sentinel-1 will provide routinely and systematically SAR data for operational monitoring tasks especially for GMES Services and National services
- Using the same SAR imaging mode (instrument settings, e.g. IW) facilitates the build-up of *data time series* for long-term continuity of observations with *equidistant* and *short time intervals (interferogram stacks)*



- TOPS burst synchronization to enable TOPS InSAR
- Sentinel-1 A & B will fly in the same orbital plane with *180 deg.* phased in orbit, each with*12-day repeat* orbit cycle
- Formation of InSAR data pairs having time intervals of *6-days*
- Small orbital tube with radius of 50m (rms) provides small InSAR baselines



⇒ **Coherent Change Detection Monitoring applications**

Monitoring of geophysical phenomena related to surface displacements and/or changes in scattering properties having different time scales (mm/year – m/day)

Thank you for your attention