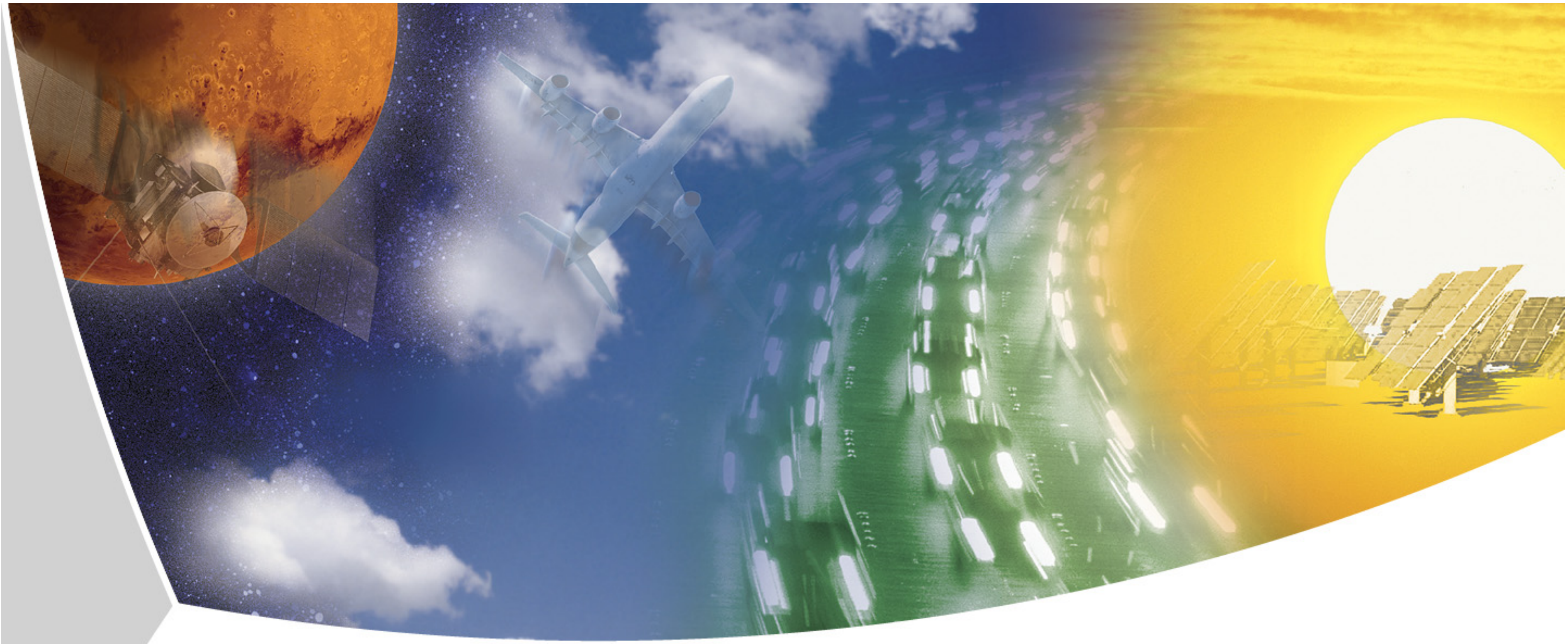

Innovative and Efficient Strategy of Calibrating Sentinel-1

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CALIBRATION

Overview

- **Sentinel-1 Objectives**
- **Challenge of Sentinel-1 Calibration**
- **Strategy / Recommendations**
  - Successful Execution of all Calibration Activities
  - Delivery of Calibrated SAR Data Products as soon as possible
- **Calibration Scenario**
  - Coverage at Mid Latitude, suitable Test Site
  - Calibration Procedures
  - In-Orbit Calibration Plan
- **Conclusion**

Sentinel-1 Objectives

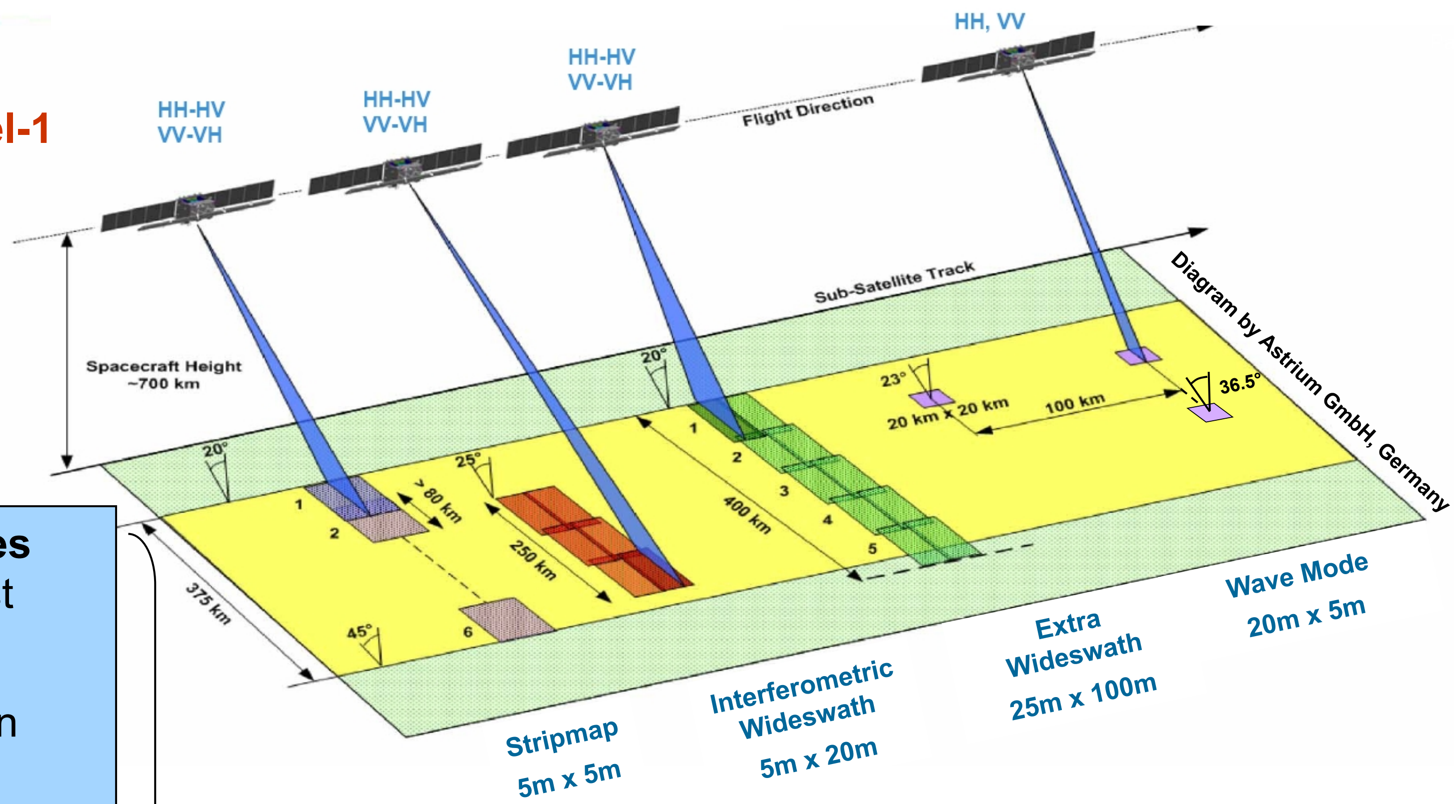
As part of the **European GMES** program the **Sentinel-1** mission is designed to provide **continuity** of SAR operational applications **in C-band** for **global earth observation** especially after the ENVISAT/ASAR will be decommissioned

Mission Life-Time	> 10 Years
SAR System	2 Satellites, Right Looking
Life-Time per Satellite	7 Years, extended to 12 Years
Orbit	- Near Polar Sun Synchronous - 693km - 175 Orbit in 12 Days Repeat Cycle - Orbit Period 98.6min
Centre Frequency	5.405 GHz (C-band)
Bandwidth	max. 100 MHz
Antenna Array	- Size 12.3m x 0.84m - 14 Tiles with 20 Phase Centres on 5 Panels - 280 T/R Modules

November 2011

Challenge

to calibrate Sentinel-1



- **4** different **Modes** operated at least over 10 Years
- Dual Polarization
- Wide Range of Swath Positions (18°-47°)
- **Tight Performance** in all Modes
  1.0dB (3σ)

→ **Commissioning Phase 3 Months** → **Efficient Calibration Strategy**

Calibration Strategy I

- **Goal**
  - reduce the calibration effort during the commissioning phase
  - ensure stable and reliable operation of a precise SAR system over a period > 10 years

- **Internal Calibration Facility**
  - compensate for drift effects by internal calibration pulses
  - derive actual **settings** of the **TRMs** by **pulse coded technique** (PCC) for tuning/ optimizing the antenna model
- **Antenna Model**
  - shift most of the antenna characterization from the CP to pre-launch activities => shift the effort from space to ground
  - provide all **reference patterns** for **radiometric correction** of the SAR data
  - derive **antenna settings** for **best** instrument **performance** even for drifting and/or failed transmit/receiver modules (TRM) during the lifetime

⟹ only a **few** selected **beams** have to be **really measured** ⟹

- short duration of 3 months CP
- reasonable effort for long term system monitoring

Calibration Strategy II

- **Relative radiometric calibration** of all SAR data products has to be **already performed** by applying:
  - internal calibration (drift compensation)
  - **shape** of the antenna **patterns**
  - **gain offset** between **different beams**

  } derived by the antenna model

- Then, **absolute radiometric calibration** can be performed by measuring the whole Sentinel-1 system against reference targets **independent of** both:
  - the **target position** within the swath and
  - the **beam** and **mode** being operated.
- Thus, **one** absolute **calibration factor** is valid for **all** operation **modes**

- Minimum **number** of **measurements** required against reference targets is defined by the **end-to-end system** calibration **budget:**
  - **worst case parameters** across **all modes** are applied
    because measurements are performed independent of beam and mode
- Hence, the end-to-end system **calibration budget** for **one specific mode** will be **better** because not all worst cases are combined by one mode.

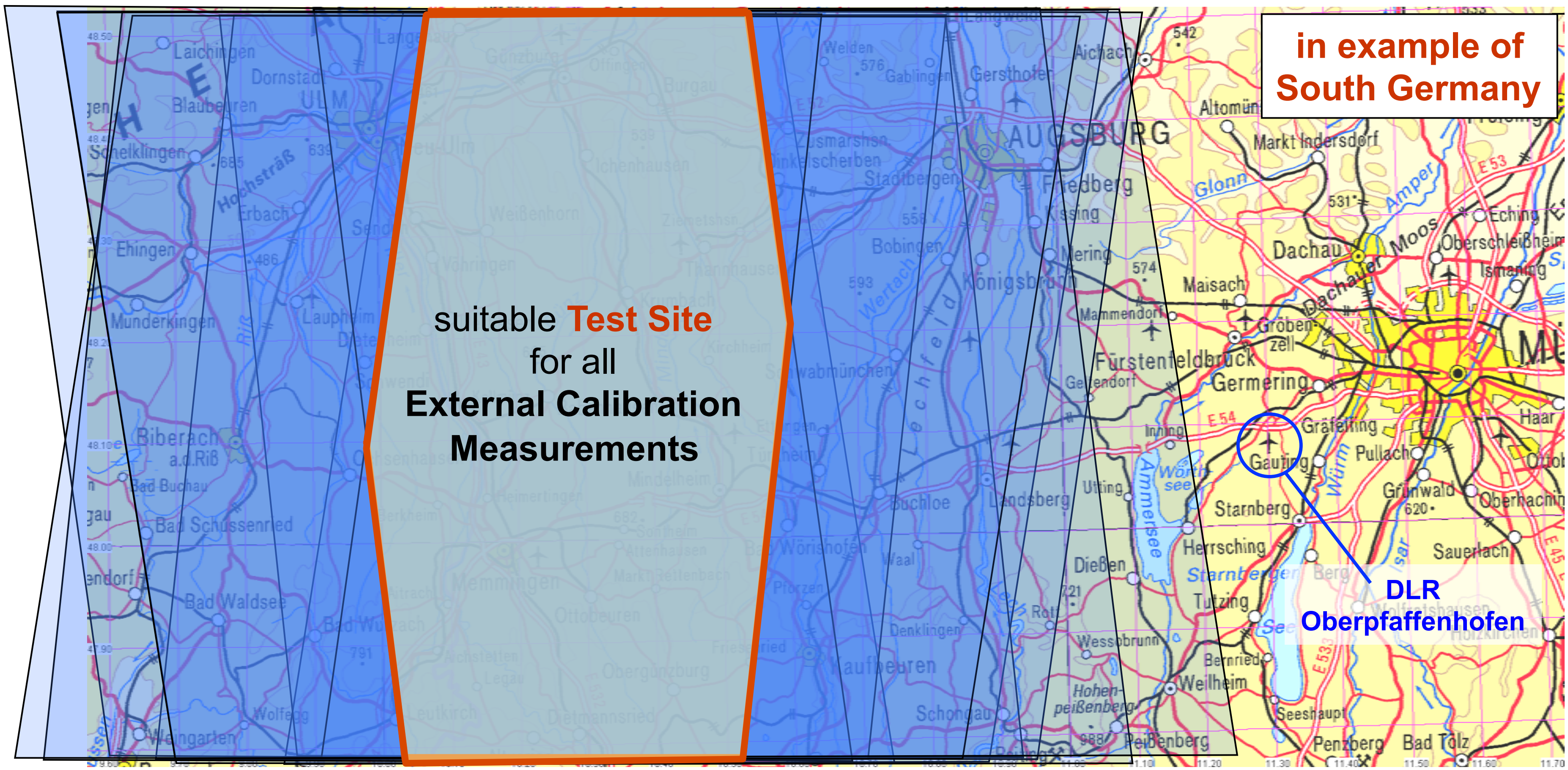
Recommendations / Rules

- **Tight Schedule of 3 months CP**
  - **Co-/cross polar** receiving channels should be measured **simultaneously**
  - Test site within **crossover area** of ascending and descending swathes
- **High Radiometric Accuracy 1dB** (3σ)
  - Measuring at least **one beam** of **each mode**
  - Against **3 reference targets** deployed **within** the **swath**
  - Measuring each selected beam **by 2 passes** (ascending/descending)
  - Measuring at least one beam with **low**, one with **mid** and one with **high incidence angle**
  - Measuring at least one beam in **both transmit polarisations**

⟹ Suitable beams for calibrating the whole Sentinel-1 system

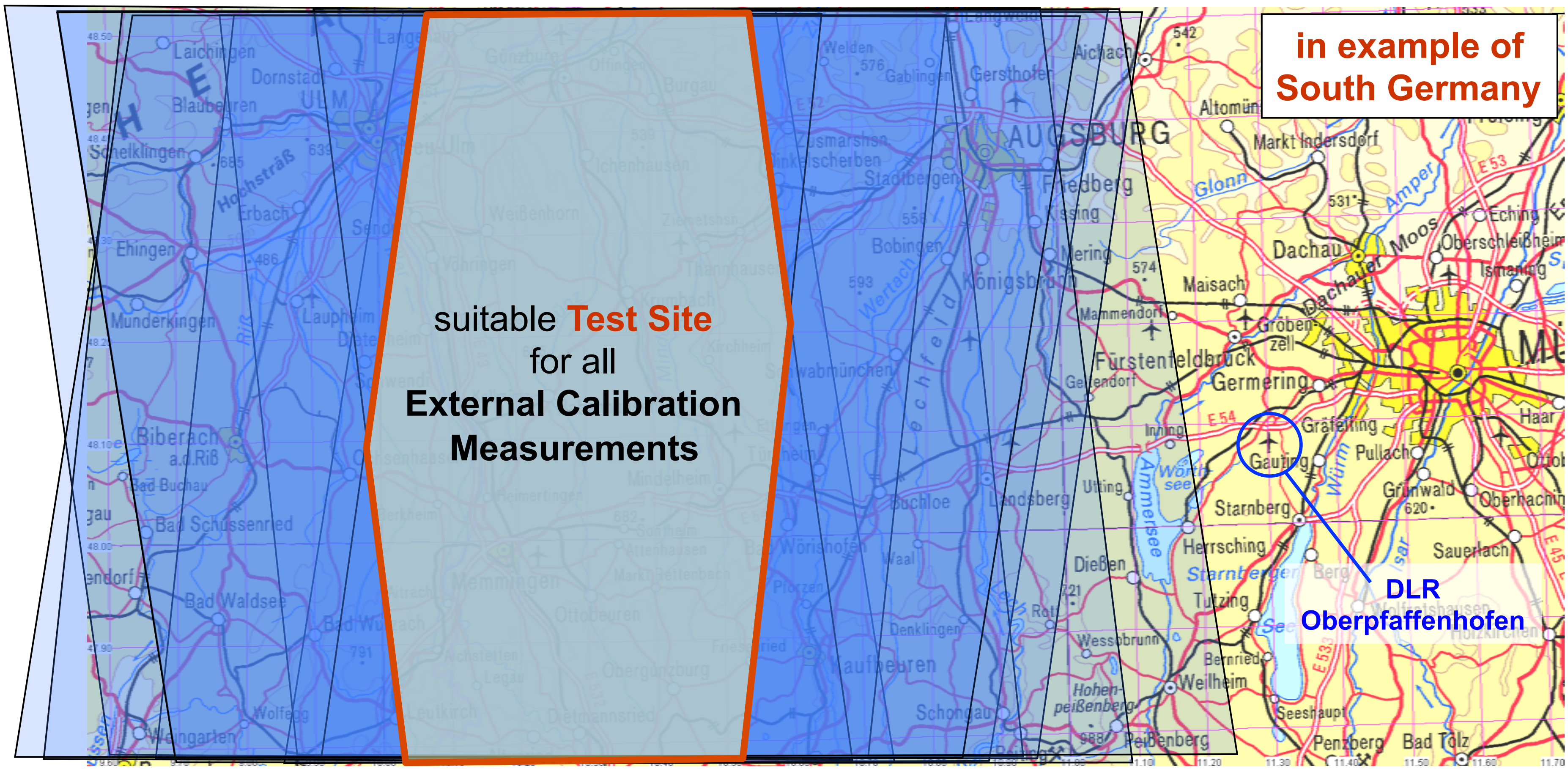
IW1, IW3, SM1, SM6, EW1, WV1

Coverage of Sentinel-1 across Mid Latitude I



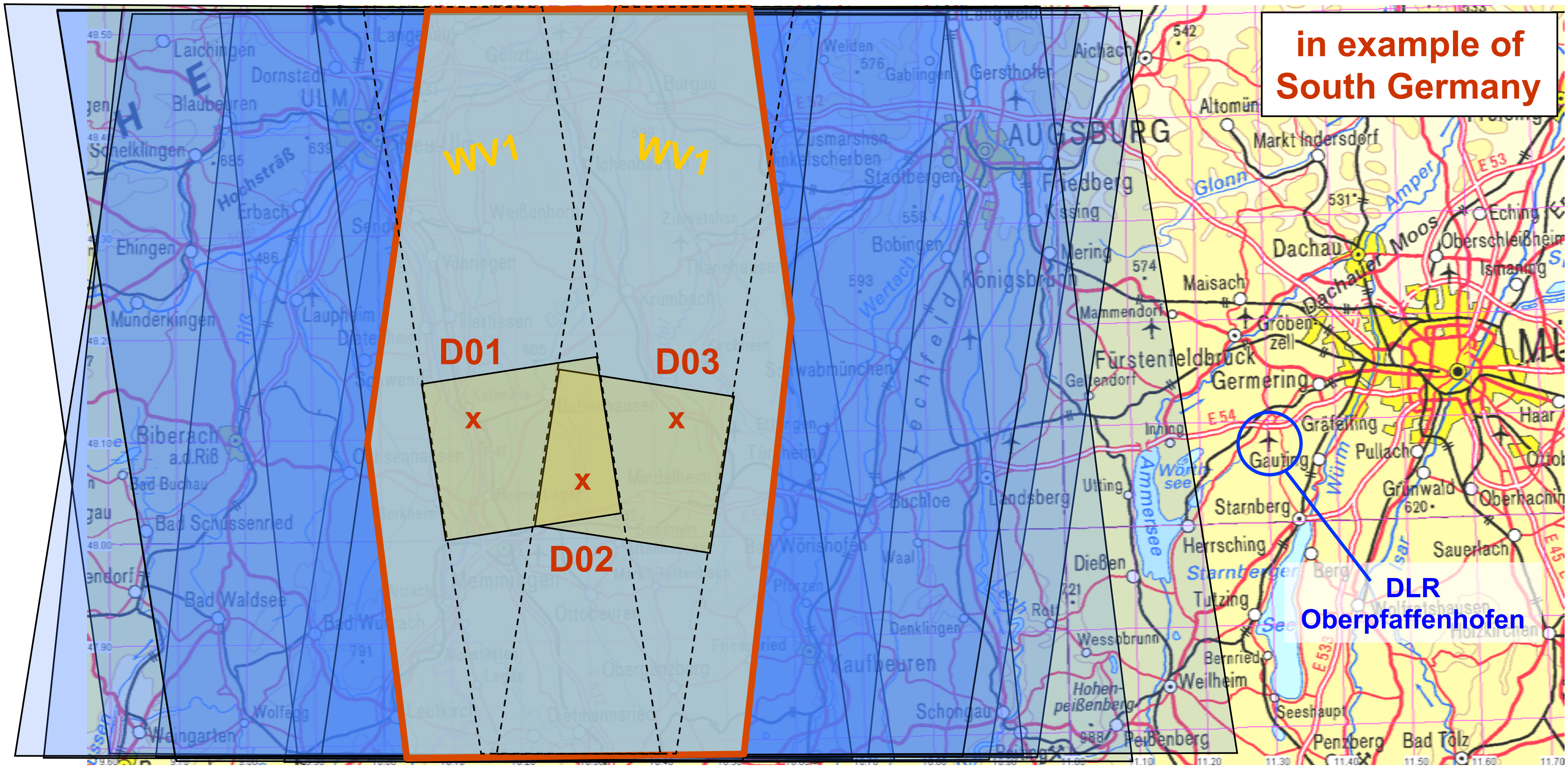
- **Cross over region** of beams**IW1, IW3, SM1, SM6, EW1**
- **Ascending** and **descending** swath for each selected beam

Coverage of Sentinel-1 across Mid Latitude II



Selection of **Target Position** → Coverage of **Wave Mode**

Coverage of Sentinel-1 across Mid Latitude III



- Cross over region of beams IW1, IW3, S1, S6, EW1 and **WM1** (asc and des)
- 3 target positions **D01 – D03** within one test site

Absolute Radiometric Calibration

Beam / Mode	1. Cycle	2. Cycle	3. Cycle
IW1	1. day (des)	1. day (des)	-
	4. day (asc)	4. day (asc)	-
IW3	8. day (des)	8. day (des)	-
	9. day (asc)	9. day (asc)	-
SM1	6. day (des)	-	-
	11. day (asc)	-	-
SM6	-	-	8. day (des)
	-	-	9. day (asc)
EW1	-	6. day (des)	-
	-	11. day (asc)	-
WM1	-	-	6. day (des)
	-	-	11. day (asc)

within **3** repeat **cycles** by **46 measurements** →

- **6** passes within **1 repeat cycle**
  - 1. day, 4. day } **IW1**
  - 8. day, 9. day } **IW3, SM6**
  - 6. day, 11. day } **SM1, EW1, WM1**
- At least **2 acquisitions** per **beam** (ascending/descending)
- Measuring at least one beam in **both** transmit **polarisations** modes (IW1/3 during the 2. repeat cycle)
- **compliant** with **end-to-end** system calibration **budget** in all modes

< 0.95 dB (3σ) (co-polar)
< 0.99 dB (3σ) (cross-polar)

Antenna Pointing

- **Rainforest**
  - 2-way notch-pattern in elevation
  - different orbits (attitude control check)

not critical with respect to the schedule

- **Ground Receiver**
  - 1-way notch-pattern in azimuth, 2 acquisitions
  - at low, mid and high incidence angle
  - 1 notch-beam in second polarisation

- **2** acquisitions per beam (asc/des)
- **3** ground receiver per test site
- **3** beams

Beam	Incidence Angle	Polarisation	Day within Repeat Cycle
ANP1	low	H	6. (des) 11. (asc)
ANP2	mid	H	1. (des)
ANP2	mid	V	4. (asc)
ANP4	high	H	8. (des) 9. (asc)

↓

18 measurements within **1** repeat **cycle**

↓

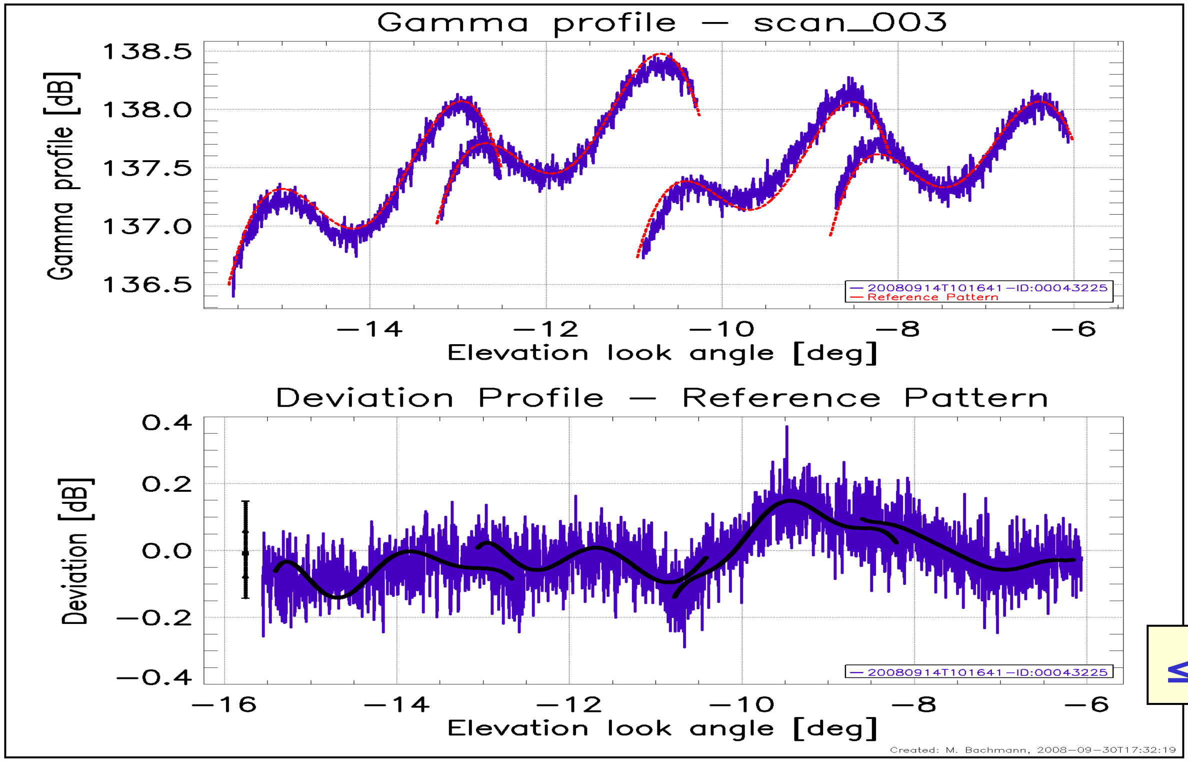
pointing knowledge

< 0.01 deg (az/el)

Antenna Model Verification (Req. 0.2dB)

- **Rainforest (Elevation Pattern)**
  - 2-way pattern, 4 acquisitions per selected beam
  - 3 StripMap beams (low, mid, high inc. angle)
  - Gain offset between different beams by IW / EW

Antenna Model Verification in Example of TerraSAR-X



purple: **gamma profile** derived across rainforest

red: **reference pattern** derived from antenna model

≤ ± 0.2dB

Shape deviation within the **main beam**

Gain offset between different **beams**

Antenna Model Verification (Req. 0.2dB)

- **Rainforest (Elevation Pattern)**
  - 2-way pattern, 4 acquisitions per selected beam
  - 3 StripMap beams (low, mid, high inc. angle)
  - Gain offset between different beams by IW / EW

not critical with respect to the schedule

- **Ground Receiver (Azimuth Pattern)**
  - 1-way pattern, 4 acquisitions per selected beam
  - S1, IW1, IW3 (low, mid, high inc. angle)

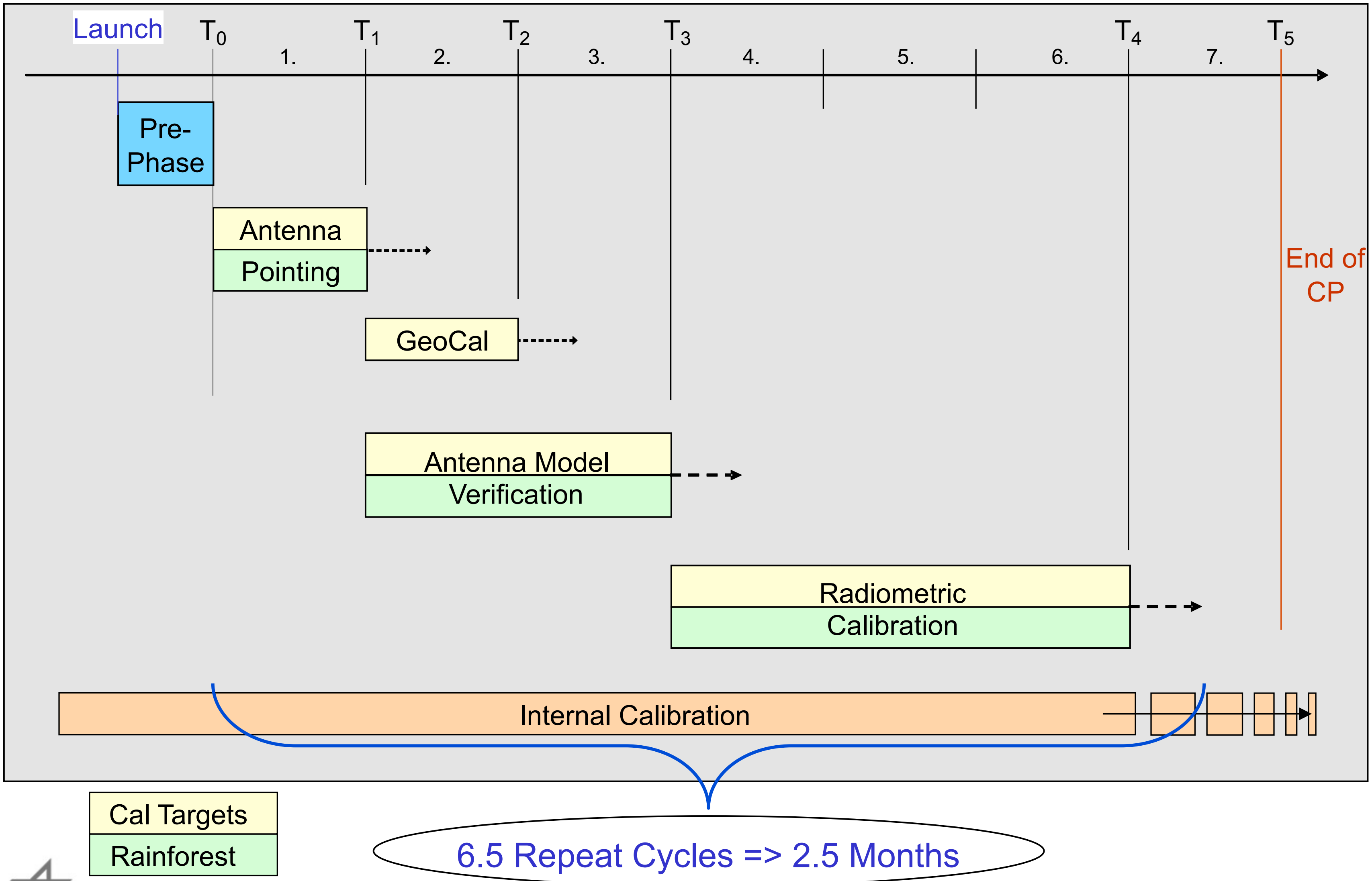
- **4** acquisitions per beam (asc/des)
- **3** ground receiver per test site
- **4** beams

36 measurements within **2** repeat **cycle**

Incidence Angle	Beam	Polarisation	Day within Repeat Cycle
low	S1	H	6. (des) 11. (asc)
mid	IW1	H	1. (des) (1. cycle) 4. (asc) (2. cycle)
mid	IW1	V	1. (des) (2. cycle) 4. (asc) (1. cycle)
high	IW3	H	8. (des) 9. (asc)

Imaging mode → **Geometric Calibration** can be performed simultaneously

In-Orbit Calibration Plan



Conclusion I

- **Efficient calibration strategy** has been developed for Sentinel-1 based on:
  - **PCC method** providing the actual setting of individual T/R modules
  - precise **antenna model** providing antenna patterns and beam-to-beam gain offsets
  - only **1** absolute **calibration factor** for **all** operation **modes**
  - different **rules/recommendations** have been established

- **6 beams** (IW1, IW3, SM1, SM6, EW1, WV1) have been selected for measurements against reference targets

- As shown in example of South Germany a **test site** with **3 transponders** at **mid latitude** is **compliant** with
  - the end-to-end system calibration **budget** in all modes: **< 1.0dB (3σ)** and
  - the **schedule** of the **commissioning phase** of 3 months

- **Long term system monitoring** has been analyzed for **different** target types
  - **3 transponders** in addition to **rainforest,** a solution with highest accuracy
  - **permanent scatterer** well **suitable** for trend analysis over **long periods,** but **not** for **evaluating** the system **directly** or over a short term