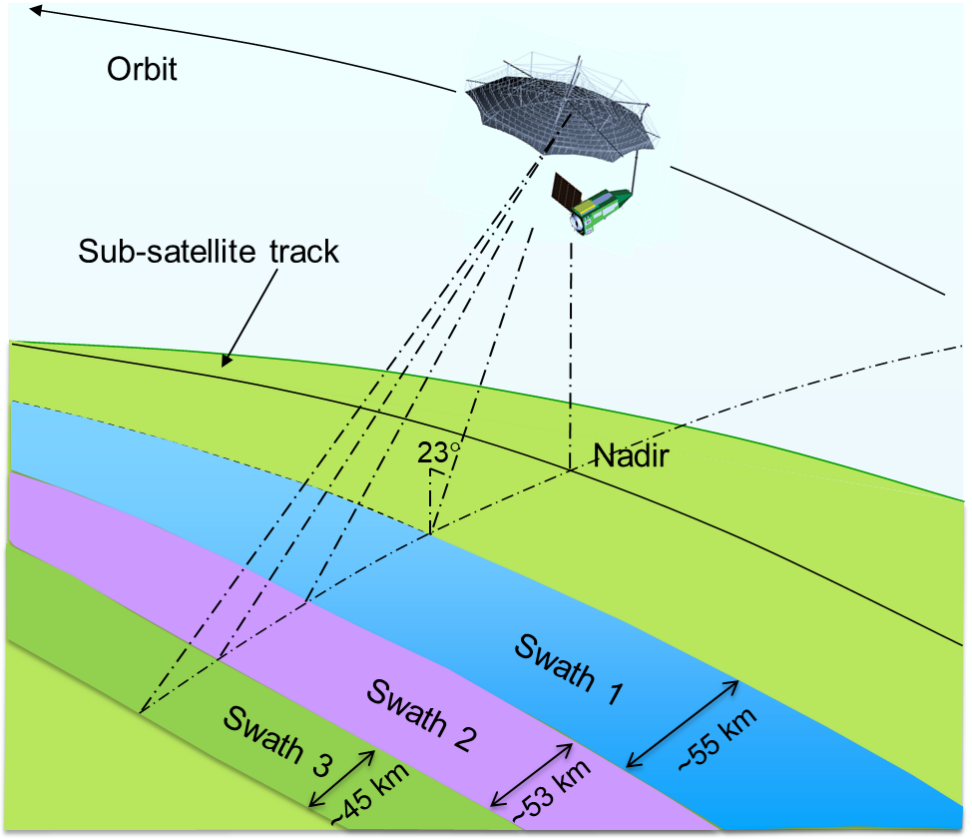
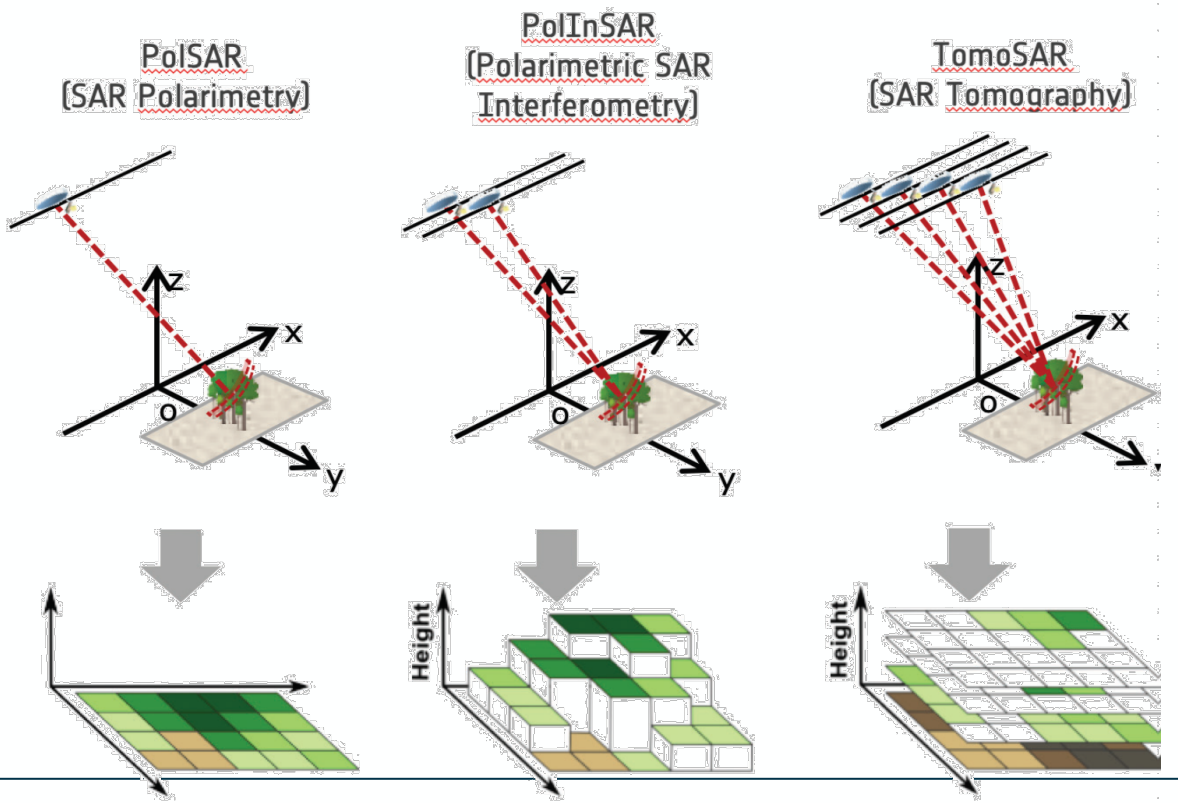
Biomass Calibration Concept towards Mission Operations

Philip Willemsen, Antonio Leanza, Adriano Carbone, Ernesto Imbembo, Bjorn Rommen, Michael Fehringer, Maktar Malik, Tristan Simon, Klaus Scipal

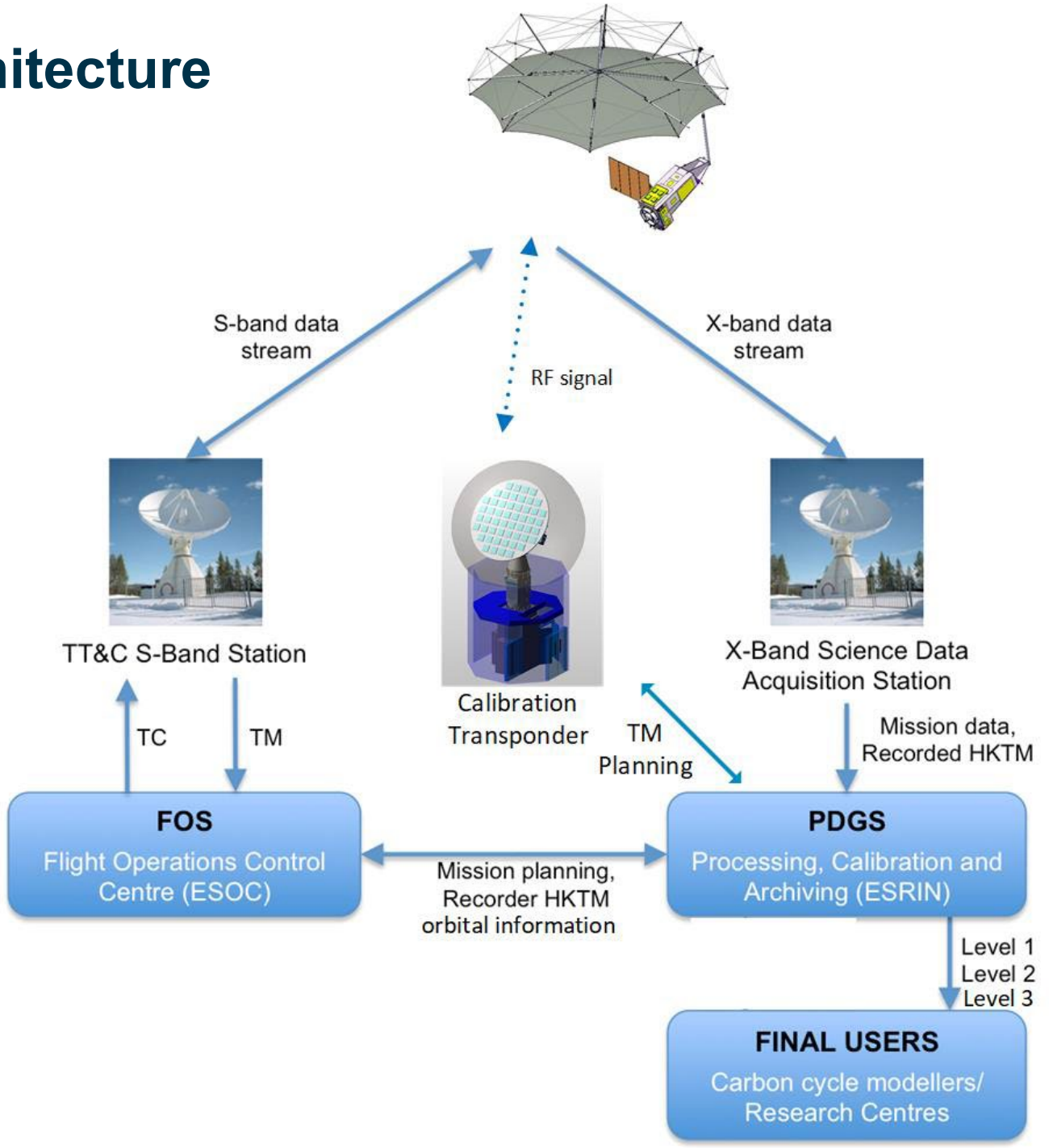
Biomass mission overview

- Fully linear polarimetric side-looking stripmap mode SAR, P-band: 435 MHz, total bandwidth: 6 MHz
- total swath ~150 km, obtained by satellite roll steering
- Tomographic phase: 7 acquisitions; Interferometric phase: 3 acquisitions





Biomass system architecture



Biomass key performance requirements

Parameter	Value	Level
Channel Imbalance	≤ -25 dB, Tx and Rx combined	Level 1a
Cross-Talk	≤ -30 dB	Level 1a
Radiometric bias	≤ 0.3 dB	Level 1b
Radiometric stability	≤ 0.5 dB	Level 1b
Noise Equivalent Sigma Nought	≤ -27 dB	Level 1b
Total Ambiguity Ratio	≤ -18 dB	Level 1b
Spatial resolution, cross-track and along track	60 m x 50 m	Level 1b
Residual phase error, standard deviation	≤ 10 deg, over pulse travel and data take time (12 min)	Level 1a
Peak Sidelobe Ratio	≤ -16 dB	Level 1b
Integrated Sidelobe Ratio	≤ -9 dB	Level 1b
Geo-location accuracy	Better than 25 m	
Dynamic range	-30dB to 5 dB	

Biomass calibration drivers

- P-Band
  - Strong ionosphere perturbation
- Satellite antenna system with a 12 metres projected aperture reflector
  - No suitable ground testing facilities to perform the e2e antenna pattern characterisation on-ground

  → Need for in-flight antenna pattern characterisation
- Space Objects Tracking Radars (SOTR) exclusion zones
  - Limitations on calibration site choices
- Dawn-dusk sun-synchronous drifting orbit, repeat cycle of 3 days
  - Infrequent target revisits

Biomass calibration concept outline

- Calibration: the parameter is measured and corrections are applied
    - The calibration process must include all contributing factors:

      SAR instrument, Platform, Propagation path, Ground Processing chain.
- Verification: the parameter is only measured / estimated, no corrections are applied

Internal calibration:

- at instrument level during the in-flight acquisitions
- amplitude and phase measurements
- send to Ground together with the science raw data to be used during the Ground Processing

External calibration:

- requires the use of ground based reference targets with known properties

Biomass calibration concept outline

- Pre-launch / on-ground:
  - characterisation of the instrument and lower level electronics (e.g. gain and phase measurements)

- In-flight:
  - The bulk of the in-flight characterisation and calibration activities is carried out during the in-flight commissioning phase:
    - System functional commissioning, characterisation & calibration
      - Platform & instrument functional commissioning
      - Antenna pattern characterization
      - Radiometric calibration
      - Polarimetric Calibration
      - Geometric calibration
    - System (performance) Verification
    - Long-Term Monitoring initialisation
    - Cal/val/ preliminary science activities

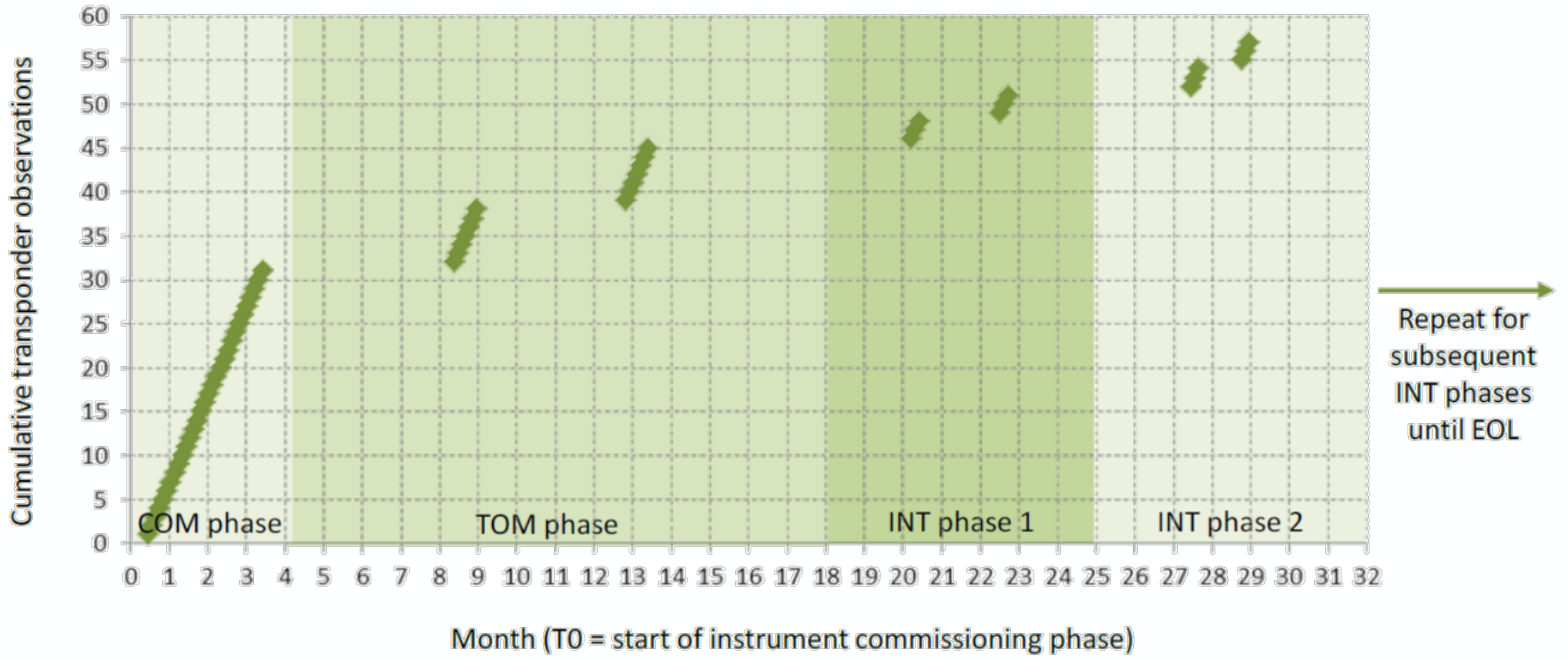
Biomass in-flight calibration targets

- Biomass Active Polarimetric Calibration Transponder
  - Satellite antenna pattern characterisation
  - System calibration
  - Performance verification

- Targets of Opportunity with known scattering properties: e.g. man-made targets, Oceans, Deserts, Ice sheets
  - TBC: as back-up and complement to antenna pattern characterisation, calibration
  - Characterisation of the system over the orbit (e.g. polarimetry)
  - Performance verification (e.g. NESN)
  - Long-Term Monitoring initialisation

Biomass Transponder utilisation

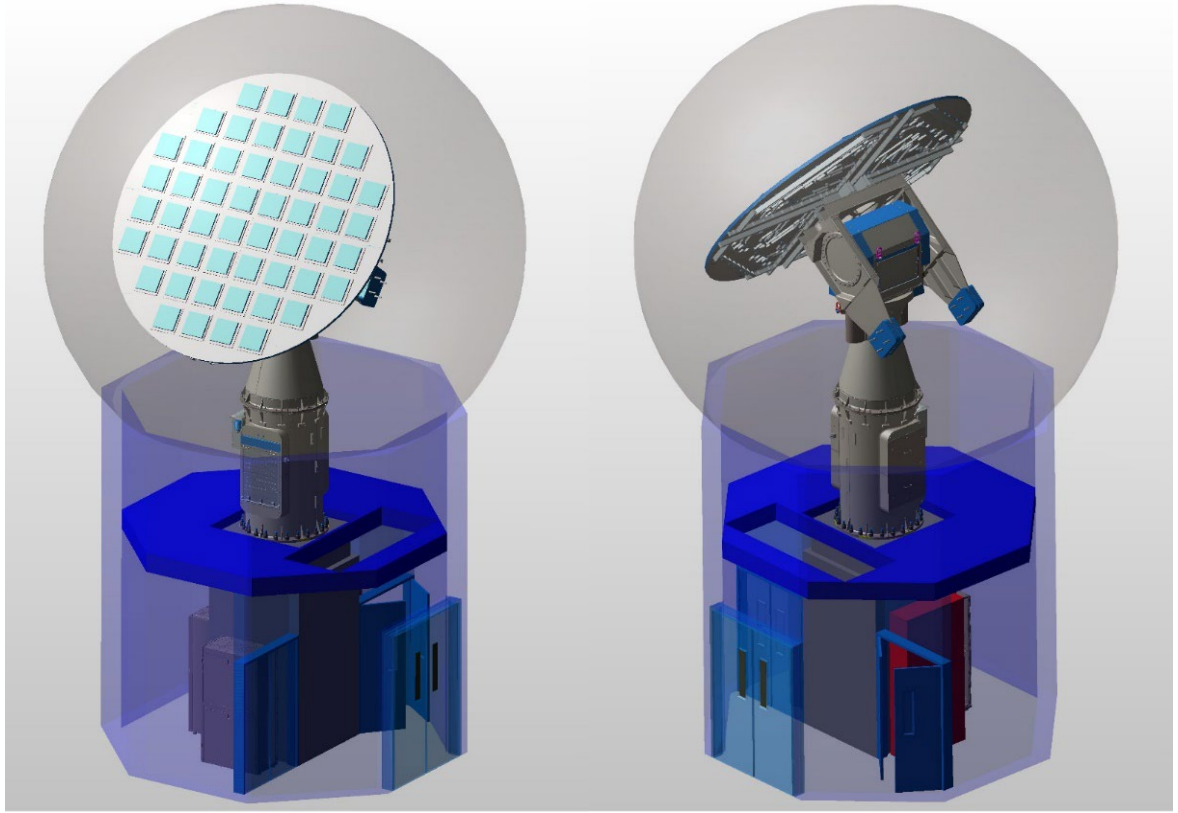
- Extensive use during the commissioning phase (calibration / verification)
- Sporadic use during the operational phase (monitoring)



Transponder description

- first of its kind, active, fully polarimetric P-band transponder, four independent polarimetric signature matrices
- satellite tracking in Azimuth/Elevation

Feature	Description
Antenna design	2D array with a 4.8 diameter. 4 quarter composed by 13 patches each (10 active)
Antenna Beam	12 deg HPBW. Gain 21.5 dBi
Simulated RCS	85 dB(m^2) with an uncertainty < 0.2 dB (1σ)
Gain stability	< 0.1 dB (1σ) over the entire mission lifetime
Sensitivity	Capability to detect PFD > -90 dBm/m^2
Cross-Polar isolation	< 40 dB (1-way) in both Tx and Rx
Channel Imbalance	< 0.1 dB (1σ) in amplitude and < 0.77 deg (1σ) in phase, including the antenna (2-way)
Signal to Multipath Ratio	> 43.5 dB
Steering	Azimuth and Elevation. Biomass tracked during the overpass
Absolute pointing error	< 0.5 deg (3σ) azimuth and elevation combined
Calibration	Internal calibration network (I-CAL) + External calibration disk with a known RCS (Ex-CAL)
Operational Modes	3 operational modes that can be run in any combination (details in the next slide)

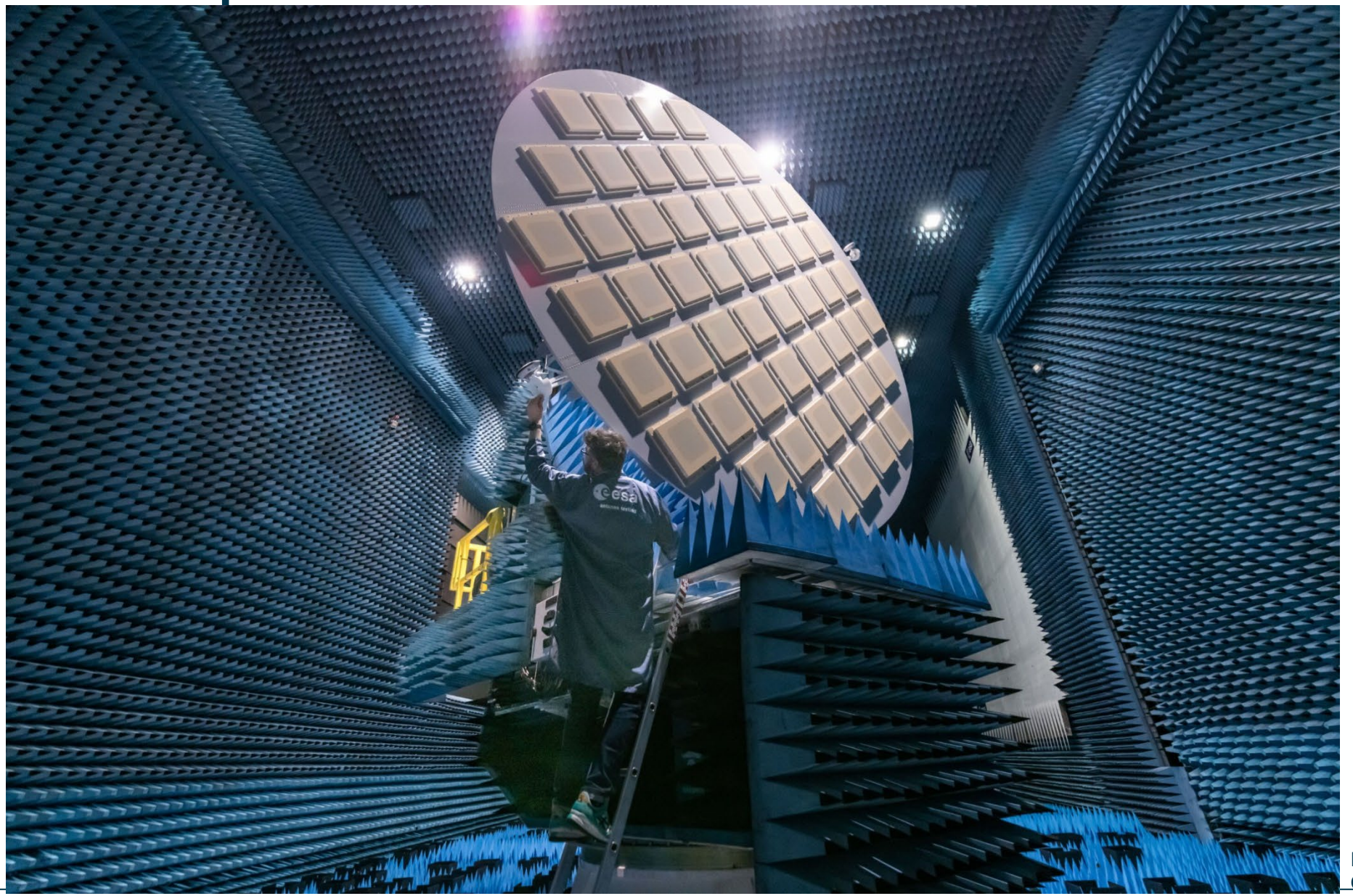


Courtesy C-Core

Biomass Calibration Transponder

- Supplied by C-Core / Canada
- Major sub-systems:
  - Antenna & Radome: Ingegneria Dei Sistemi S.p.A, (IDS) / Italy
  - Positioner: commercial-off-the-shelf / designed and manufactured by HITEC / Luxembourg
  - Control & Microwave Subsystem / CMS:
    - Microwave-subsystem: dual-channel P-band transceiver doing signal conversion, gain control & diagnostics
    - Digital sub-system: data acquisition and signal processor
    - Self-calibration unit
    - CMS host: central control entity incl. Monitoring and Control Software
  - Transponder Calibration Subsystem: disk with known Radar Cross Section at defined distance

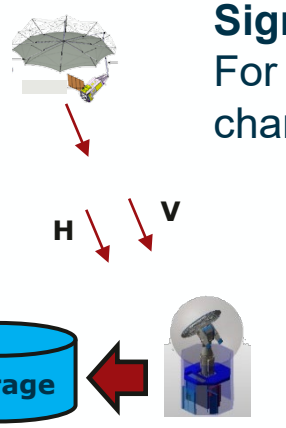
Biomass Transponder antenna



ESA-SJM Photography
Courtesy IDS, C-Core, ESA

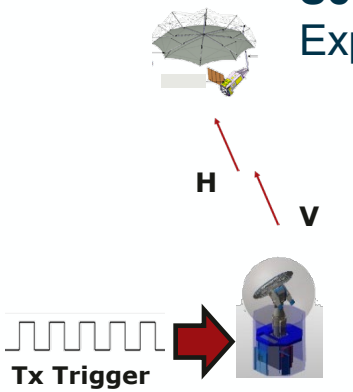
Transponder Modes

Three mutually inclusive modes:



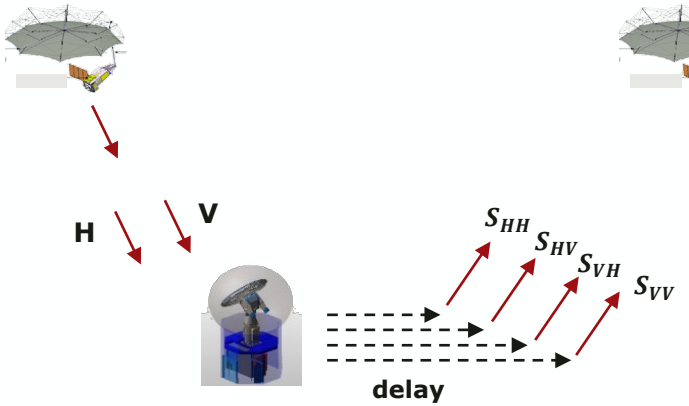
Signal Acquisition Mode (SAM)
For Antenna pattern characterisation

During the observation interval, the transponder records the received signal for both H and V polarisations.



Self-generated Transmit Mode (STM)
Experimental mode

Transponder transmits toward Biomass delayed H and V pulses generated by the transponder itself.
The transmission can be triggered by the detection of a pulse received from Biomass or according to a timeline synchronized with the Biomass Rx window (beacon mode)



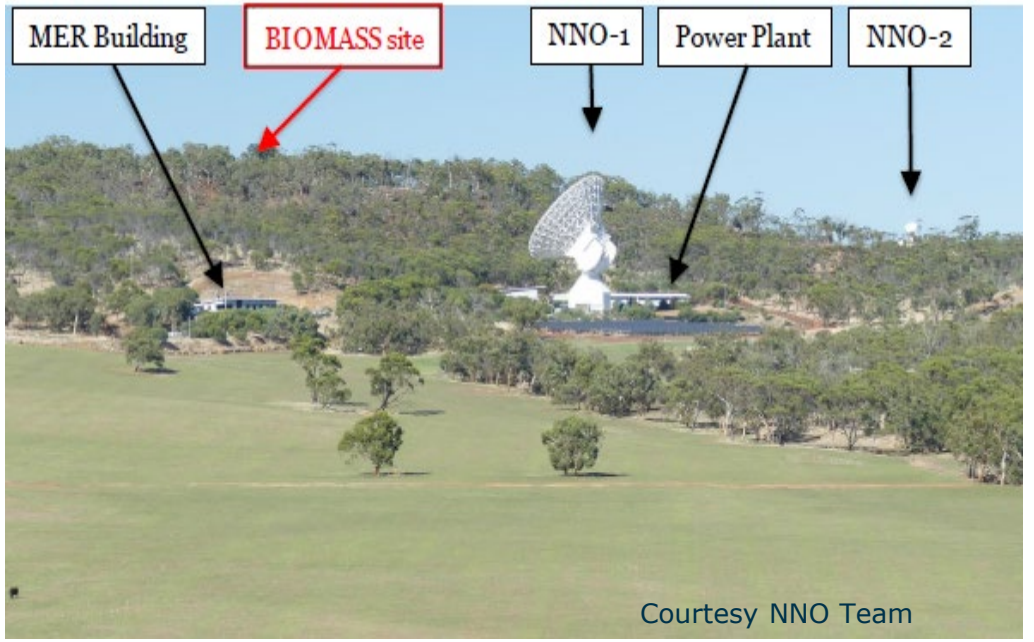
Echo Generation Mode (EGM)
For system calibration: radiometry, polarimetry, geometry

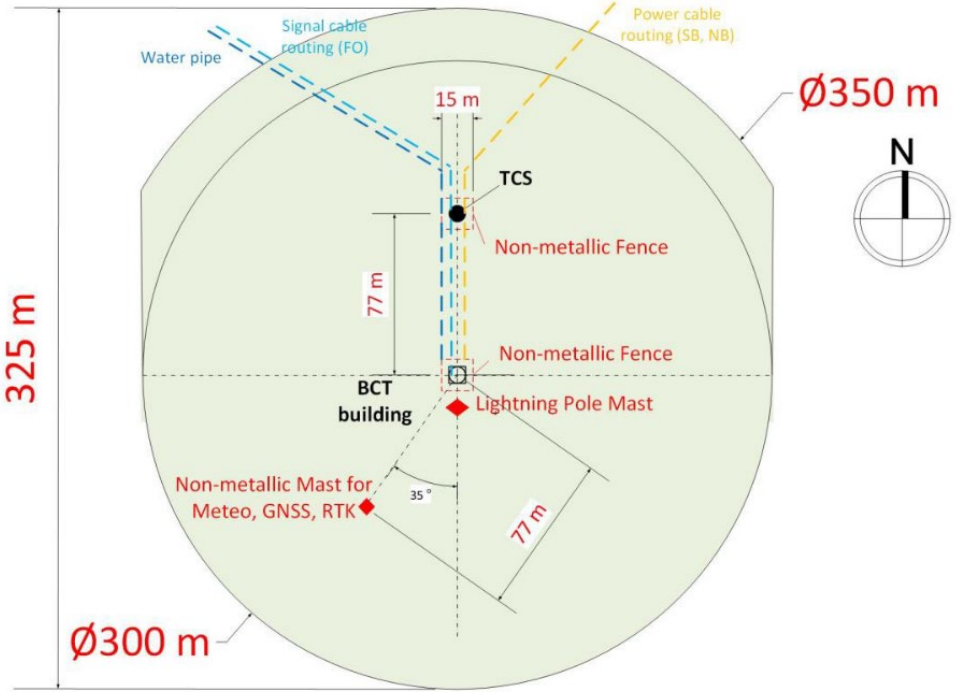
The detection of a received pulse, triggers the re-transmission of four delayed pulses, each one associated with a polarimetric signature and properly amplified to simulate a given RCS.

$$S_{HH} = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}; \quad S_{HV} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}; \quad S_{VH} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}; \quad S_{VV} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

Transponder Site

- Transponder site, foundation and antenna building supplied by ESA / ESOC, New Norcia – Western Australia
- Site driving requirements:
  - mid-latitude location for ionospheric effects compensation (e.g. Faraday rotation)
  - Flat area, low elevation, cleaned to minimise Signal-to-multipath ratio and clutter
  - Low RF background to limit Radio Frequency Interference (P-band is assumed to be more affected than higher frequencies)





Biomass E2E performance simulator

- developed and supplied by DLR Microwaves & Radar Institute
- Comprises the Front End for scenario generation and
- The Ground Prototype Processor, GPP implementing the data processing chain to perform the image processing: The GPP SW/code/modules are re-used in the development of the operational processor
- The GPP will be used during the commissioning phase
    - Level 0 & L0/L1 processor: RAW to L0 product conversion and L0 to L1 chain
    - External Calibration Processor Module: antenna pattern calculation, CCDB updating and calibration

- Mission Algorithm and Analysis Platform (MAAP)

Performance Parameters

Parameter	Cal/Ver/Char/Mon	Baseline Target	ToO usability	Application Level
Antenna Pattern	Characterisation	Transponder	Yes (elev.)	L0 (RC)
Calibration Constant	Calibration	Transponder	Yes, if RCS known	L1a
Effective Number of Looks	Verification	Scene	Yes	L1b
Noise Equivalent Sigma Nought	Verification	Scene	Yes	L1b
Radiometric Bias	Calibration	Transponder	No	L1b
Radiometric Stability	Verification	Transponder	Yes	L1b
Total Ambiguity Ratio	Verification	BEEPS	No	L1b
Peak to Side Lobe Ratio	Verification	Transponder	Yes	L1b
Integrated Side Lobe Ratio	Verification	Transponder	Yes	L1b
Cross-Talk	Cal / Ver	Transponder	Yes	L1a
Channel Imbalance	Cal / Ver	Transponder	Yes	L1a
Across-Track resolution	Verification	Transponder	Yes	L1b
Along-Track resolution	Verification	Transponder	Yes	L1b
Geo Location accuracy	Calibration	Transponder	Yes	L1b
Antenna Pointing	Characterisation	Transponder	Yes	L0 (RC)
Residual Phase Error	Verification	BEEPS	No	L1a
Interf. Common Doppler BW	Verification	Scene	Yes	L1a
FR and TEC	Calibration	Transp / Scene	Yes	L0/L1a

RADIOMETRIC

POLARIMETRIC

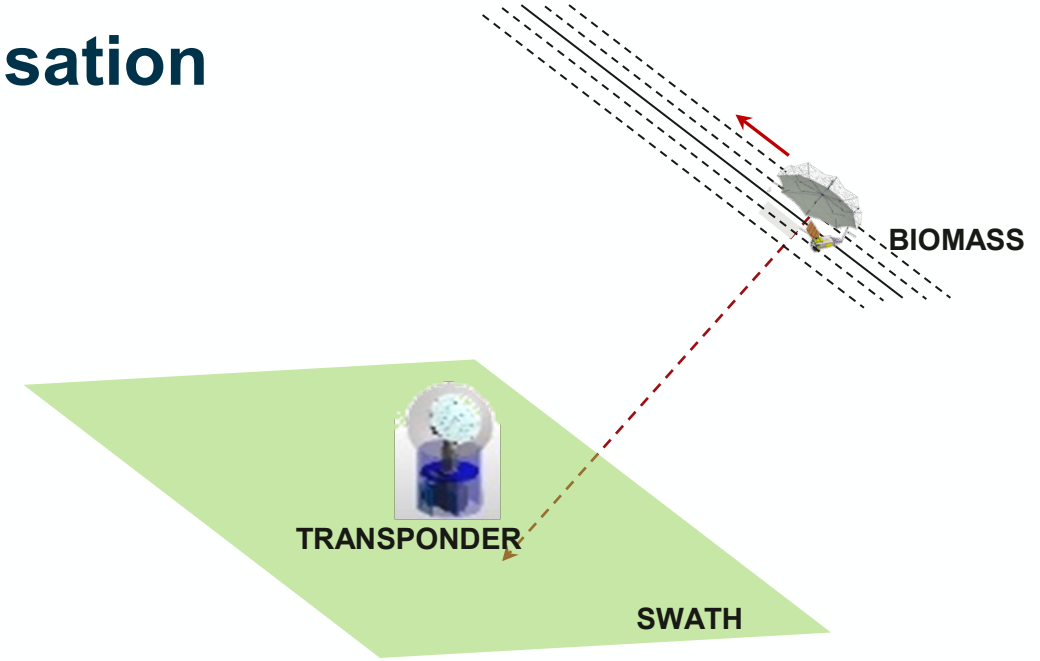
GEOMETRIC

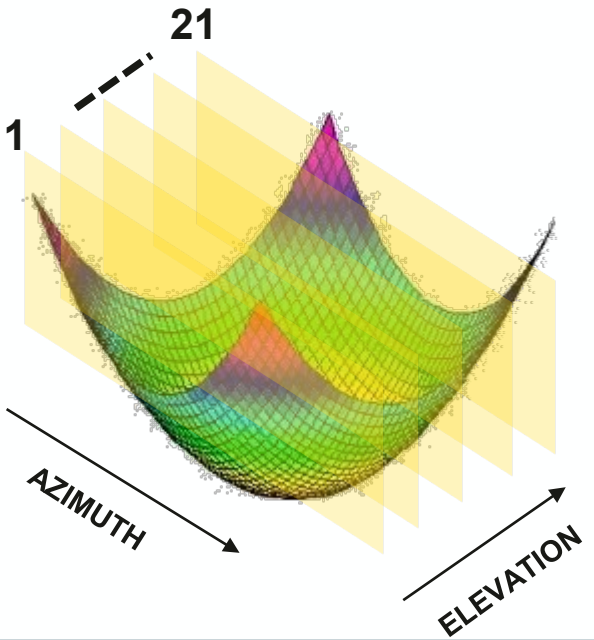
INTERFEROMETRIC

IONOSPHERIC

In-flight antenna pattern characterisation

- Antenna patterns 2D sampled: sets of azimuth measurements collected during 21 transponder overpasses with a drifting orbit (i.e. at different elevations)
- Measurements consist of pulses received by the transponder, range compressed and normalised.
- Four different antenna patterns obtained: Two doublet level(*) antenna patterns, for each polarisation H and V





(*) Biomass Feed array consist of 2 x 2 elements, fed by 2 power amplifiers. The couple of array elements fed by the same amplifier is called Doublet (D1 and D2)

Biomass calibration activities preparation status

- System and Ground Segment CDRs completed; Satellite and Instrument Flight HW manufacturing and testing on-going
- Transponder Final Model HW/SW manufacturing started
- Transponder Antenna manufacturing completed & tested with very good performance
- Transponder site construction work to be started this month
- Ground Prototype Processor development on-going
- Detailed commissioning phase activity definitions started
- Biomass satellite due for launch in December 2023

Biomass CAL/VAL Announcement of Opportunity (AO)

AO objectives:

1. to solicit **worldwide** proposals on calibration and validation (CAL/VAL)
2. to invite new research groups to participate in Biomass CAL/VAL

- As a CAL/VAL PI or co-PI, access to Biomass products and related quality information will become available to you first-hand
- Opportunity to quickly learn & cooperate directly with other Biomass CAL/VAL PIs and to perform joint activities
- PI's whose proposals are accepted will be invited to become members of the Biomass Cal/Val Team for which the Agency will organise dedicated meetings and workshops
- An important validation element is the collection and provision of independent measurements for both primary and secondary mission objectives for the Biomass mission

Note: funding of activities solicited through CAL/VAL AOs shall be covered by national/institutional resources

Announcement to be published through ESA public website Q3/2022

Thank you for all participants to, and supporters of, the Biomass Mission who are contributing significantly to the realization of this challenging mission, including:

- Members of the ESA core development team, the ESA Ground Segment (FOS and PDGS) teams, the technical support teams in ESA and the DLR Microwaves and Radar Institute

- The Biomass industrial consortium, Airbus Defence and Space Ltd (UK), Airbus Defence and Space GmbH (Germany), C-Core (Canada) and their subcontractors and suppliers

For questions please contact:
Antonio.Leanza@esa.int
Philip.Willemsen@esa.int