Elements Towards a Cal/Val Strategy for ESA's BIOMASS Mission

(*part II*)

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Overview

(1) Introduction to BIOMASS

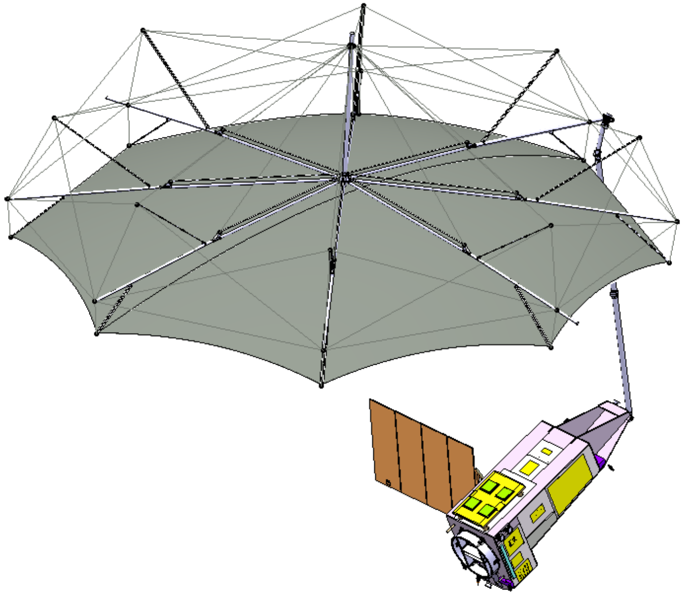
(2) Payload-related elements considered in cal/val

- Antenna model
- In-flight characterisation

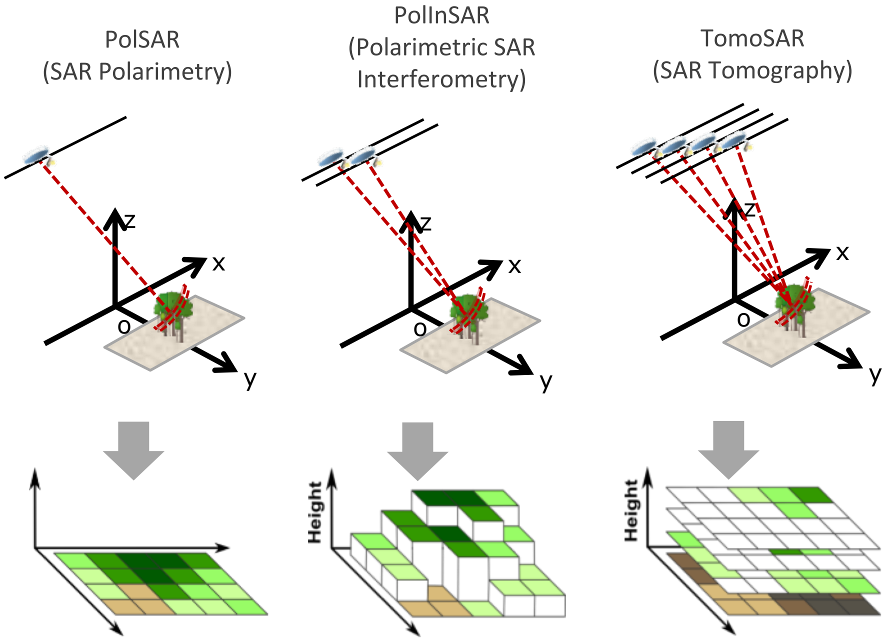
(3) Polarimetric calibration approaches

(4) Calibration targets

- Transponder
- Targets of opportunity



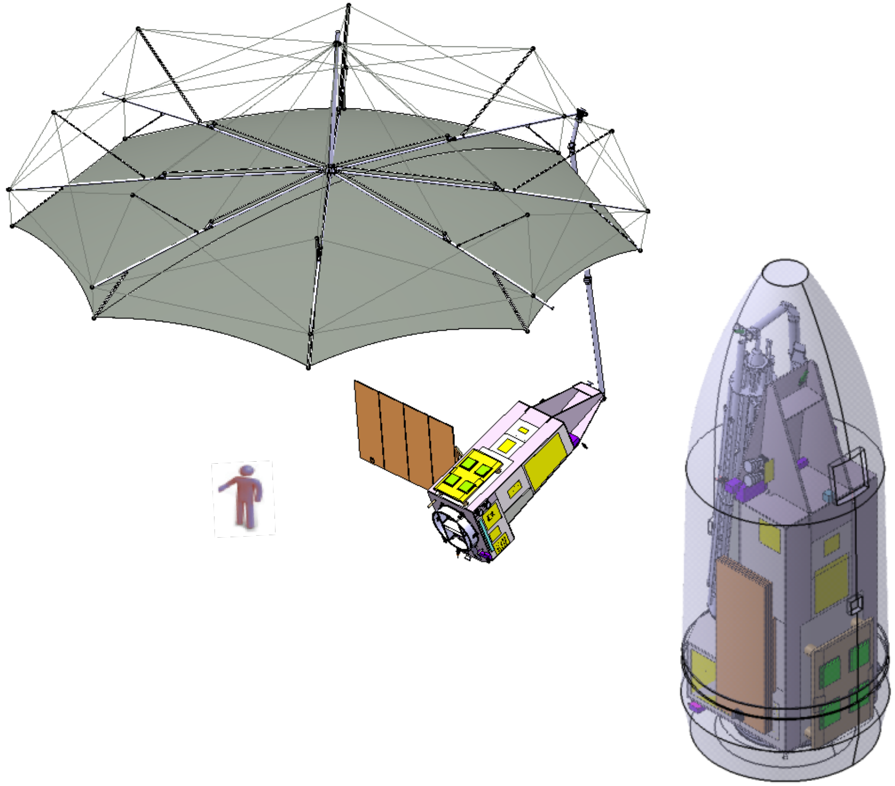
Biomass Mission Concept



- ✓ Single satellite, operated in a polar sun-synchronous orbit
- ✓ Full polarimetric P-band (435 MHz) Synthetic Aperture Radar with 6 MHz bandwidth
- ✓ 3 subswaths operated in stripmap (~50km)
- ✓ Two mission phases: Tomography (year 1), Interferometry (year 2-5)
- ✓ Multi-repeat pass interferometry (3 passes in nominal operations) with a 3 days repeat cycle
- ✓ Global coverage in ~7 months (228 days) on both asc. and des. passes
- ✓ 5 years lifetime

Biomass Mission Requirements

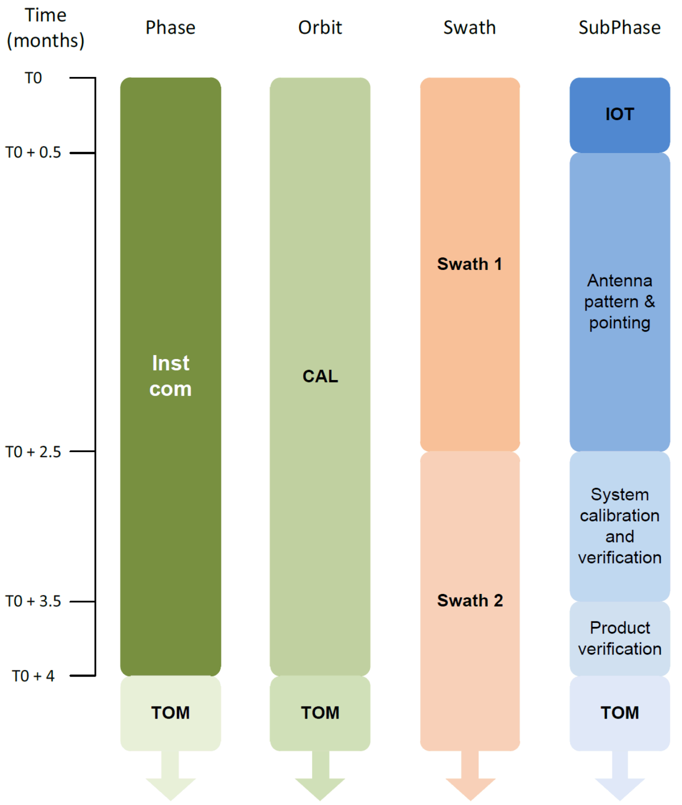
Key Parameters	
Sensitivity (NESZ)	≤ -27 dB
Total Ambiguity Ratio	≤ -18 dB
SLC resolution	≤ 60m x 8m
Dynamic Range	35 dB
Radiometric Stability	≤ 0.5 dB
Radiometric Bias	≤ 0.3 dB
Crosstalk	≤ -30 dB



BIOMASS Mission Phases

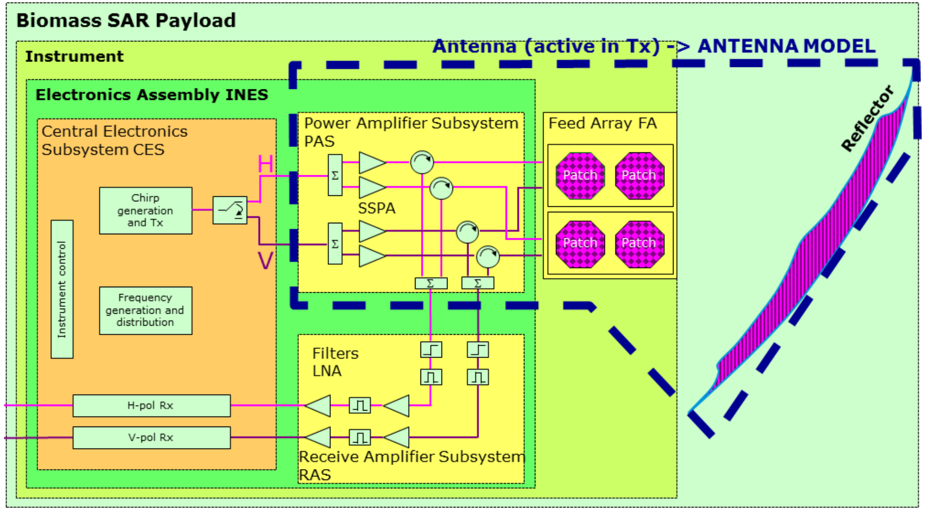
- Biomass mission phases: specific orbit for each phase
- 4 months commissioning phase planned (+2 spare months)
- Tomographic phase (TOM): 14 months
- Interferometric phase (INT): 7.5 months

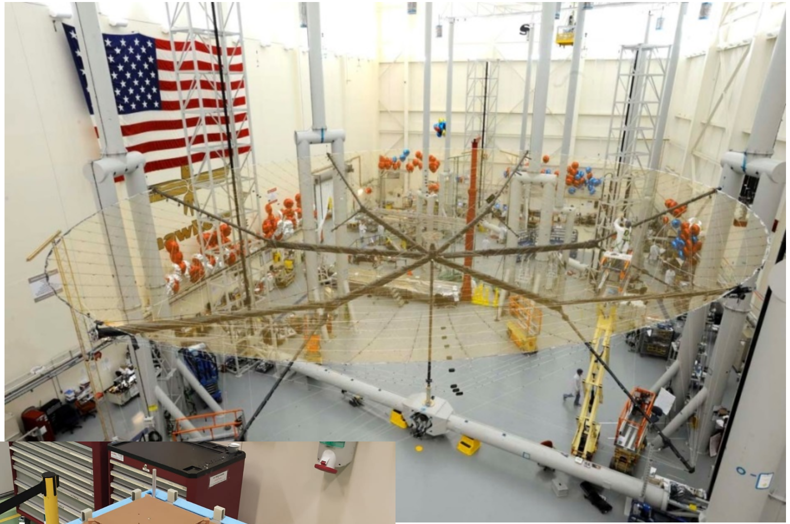
Operational Phase		Duration
Launch and Early Orbit Phase (LEOP)		<7 days
Commissioning Phase (COM)	- Platform	30 days (incl. margin, section 3.2.4.2)
	- Payload and Ground Segment	120 days (TBC, section 3.2.4.2)
Tomographic Phase (TOM)		425 days
Interferometric Phase (INT)		1400 days
End-of-Life Phase (EOL)		30 days
Total Mission Lifetime		**2012 days (5.5 years)**



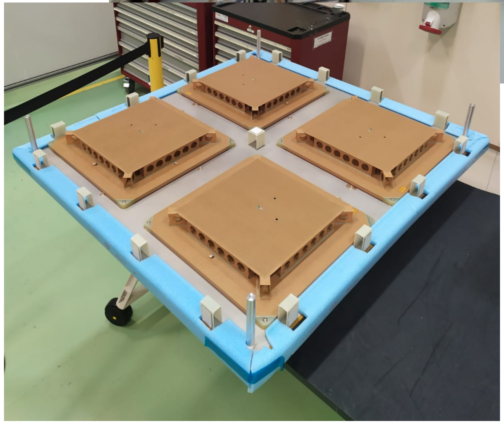
Antenna Model Purpose

- An antenna model is required for:
  - Antenna performance validation
  - Instrument calibration





12 m LDR



→ FA EQM

BIOMASS antenna validation challenges

Challenges specific to BIOMASS:

- **Size**: deployment of a 12 meters diameter LDR requires a large test facility
- **P-band**: accuracy of test facility is a challenge (e.g. quality of absorbers at P-band)
- **Mask specifications**: accurate knowledge on gain and SLL needed

→ Thus full antenna measurement is not possible and a precise characterization by model is required:

→ Errors quantification/uncertainties are needed

→ **Multi models approach** has been selected: Airbus, TAS and ESA are developing their own model on different software working with different numerical tools and modelling approach

TAS
CST: Full FA model – Ideal LDR surface

Airbus
CST + GRASP:
FA cut files – Real LDR surface – S/C

ESA
GRASP: FA cut files – Real LDR surface – S/C

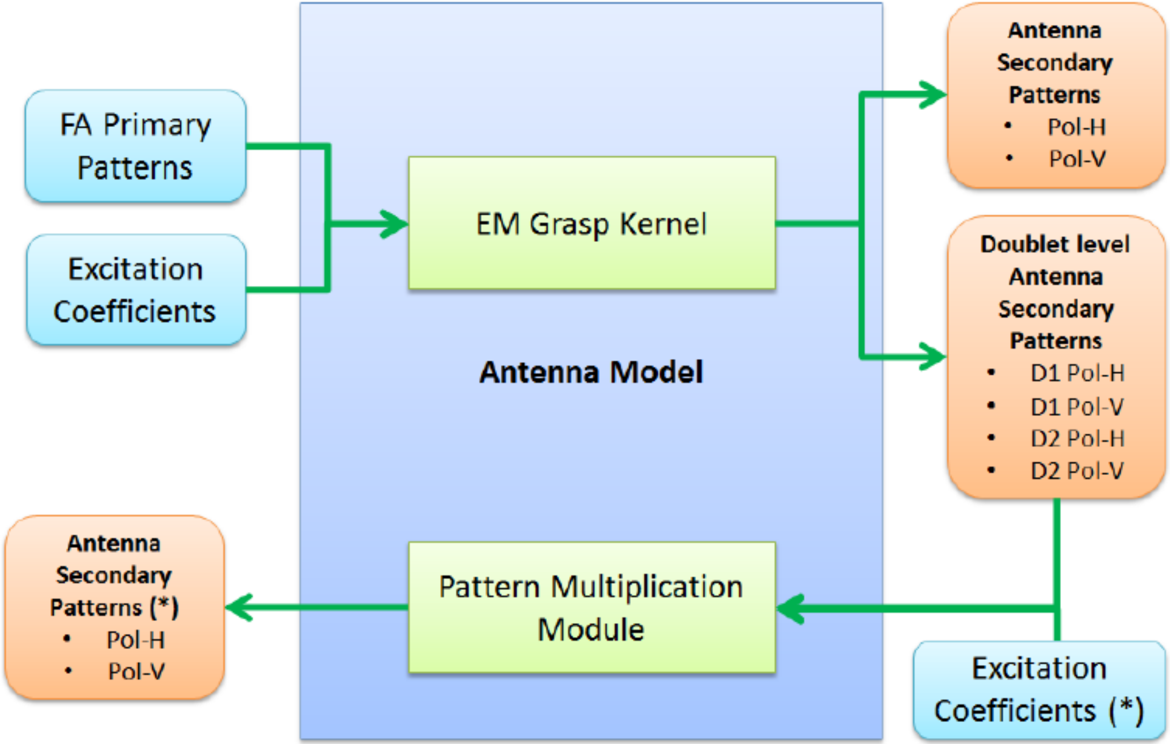
Antenna model definition

- Pattern multiplication module is implemented in Matlab at secondary level providing realized gain performance
- This approach enables to account for electronics imbalance (amplitude and phase)

→ internal cal accuracy

Further CI contributions

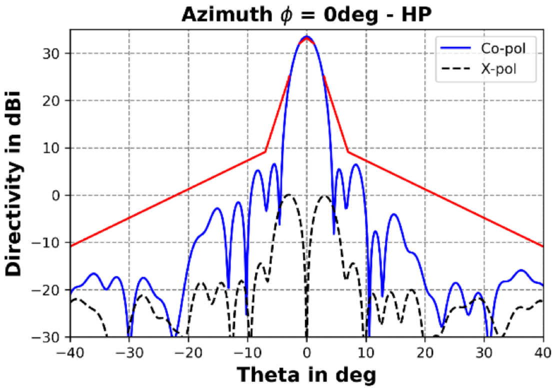
- Antenna secondary pattern knowledge
- Antenna pointing knowledge contribution (amplitude and phase gradients)

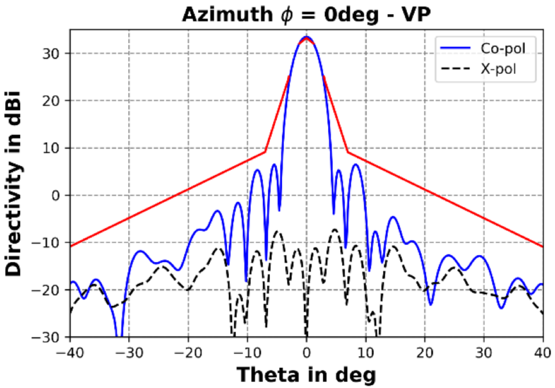


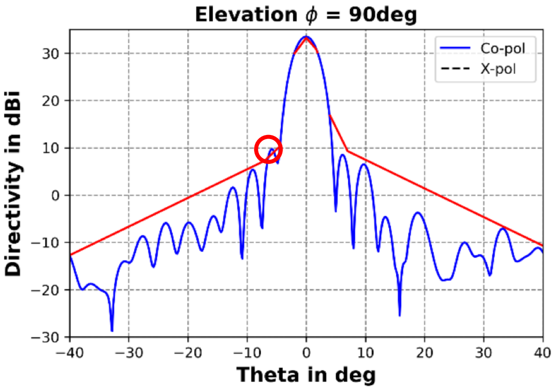
Feed array compliance status

Feed array compliance status is evaluated at secondary level for a direct link with instrument performance

- Requirement on the maximum gain envelope
- Requirements on the relative side lobe levels







Polarimetric calibration

- The measured backscatter can be represented as the combination of the non-ideal transponder RCS, Rx/Tx crosstalk, Rx/Tx channel imbalance and Faraday rotation:

$$M = \begin{pmatrix} 1 & \delta_2 \\ \delta_1 & f_1 \end{pmatrix} \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \begin{pmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{pmatrix} \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix} + \begin{pmatrix} N_{hh} & N_{vh} \\ N_{hv} & N_{vv} \end{pmatrix}$$

Crosstalks Channel Imbalances | Faraday Rotation | Transponder Backscatter | Faraday Rotation | Crosstalks Channel Imbalances | Noise + Clutter

- One equation of this form is obtained for each BIOMASS polarimetric mode
- One overpass provides a single measurement of the system
- One chance to accurately determine the system errors
- A system of complex equations difficult to solve accurately!
- 99% confidence level used for PARC analyses

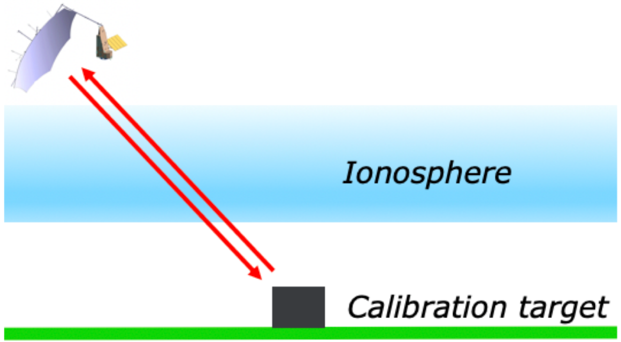
How to solve the calibration problem

2 Methods:

Analytical

- Assume that the transponder is ideal
- We can algebraically solve the system of equations
- Non-idealities in the transponder will bias the solution

→ [Chen & Quegan, 2010, 2011]



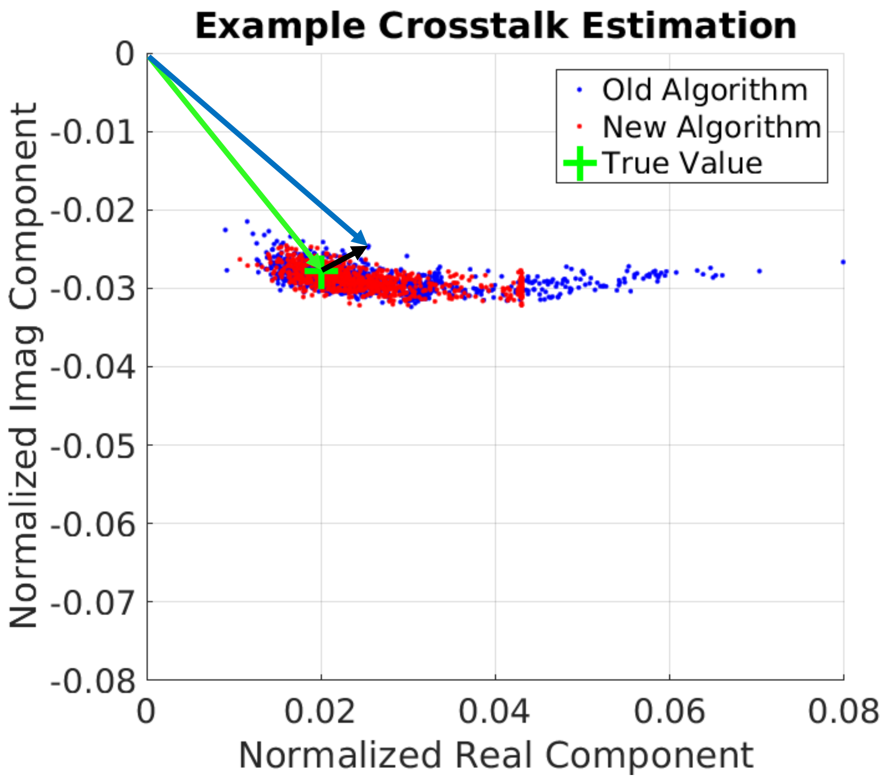
Monte-Carlo

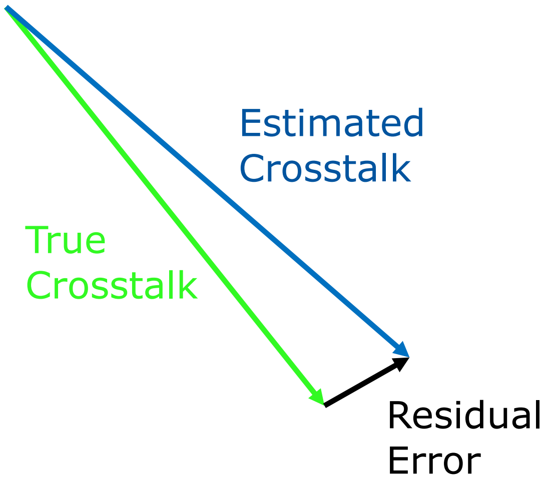
- Define a cost function which represents the level of error in the solution
- Use a numerical solver to minimize the cost function
- Seed the solver with many random initial conditions and keep the best solution
- Minimization of:

$$C(M, \hat{x}) = \sum_{i,j=1}^{4,4} |M_{i,j} - \hat{M}_{i,j}|$$

- Evolved from [Quegan & Lomas, 2015]

Defining the performance metric





$$E_{dB} = 20\log_{10}|Est - True|$$

Results (5000 runs)

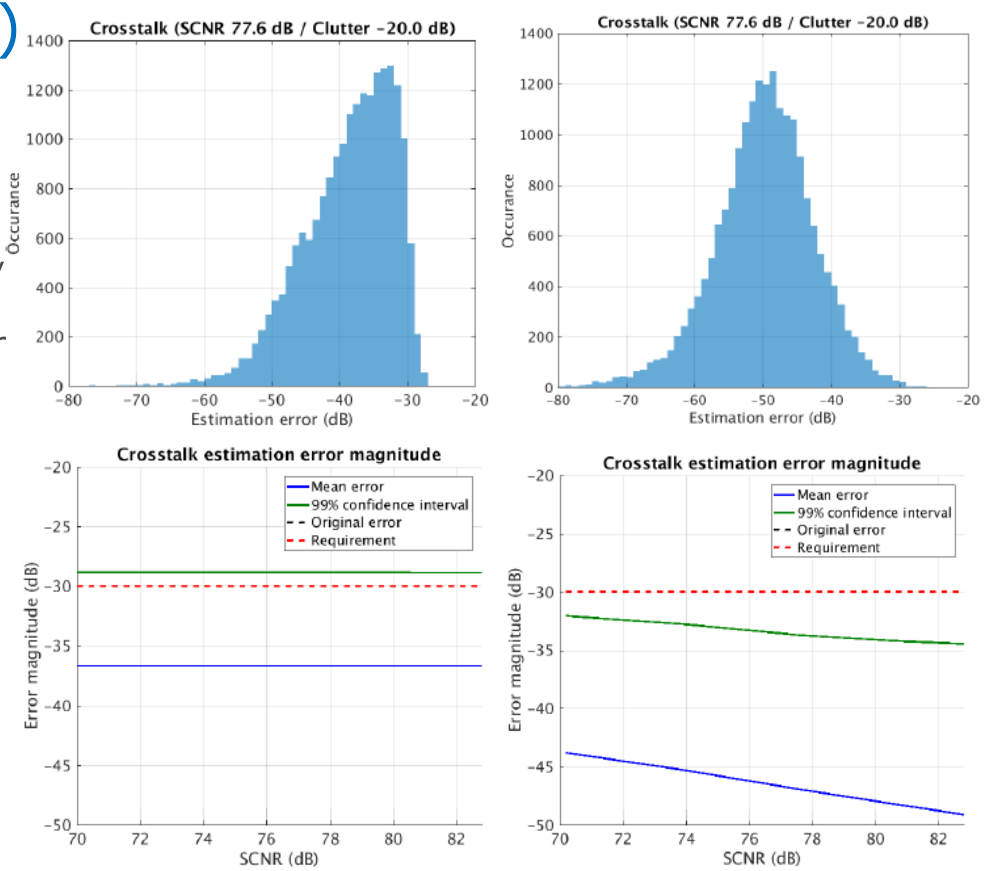
Crosstalk estimation error

- Analytical method does not accurately estimate the crosstalks, and is unaffected by noise and clutter. At high SCNR the bias due to the transponder dominates the solution

- Monte Carlo method is able to accurately estimate the crosstalk, and the solution continues to improve as noise+clutter decrease

- Transponder RCS: 85 dBm^2

Clutter (dB)	SCNR (dB)
-10	68.26
-15	73.08
-20	77.55
-25	81.22



(a) Analytical method.

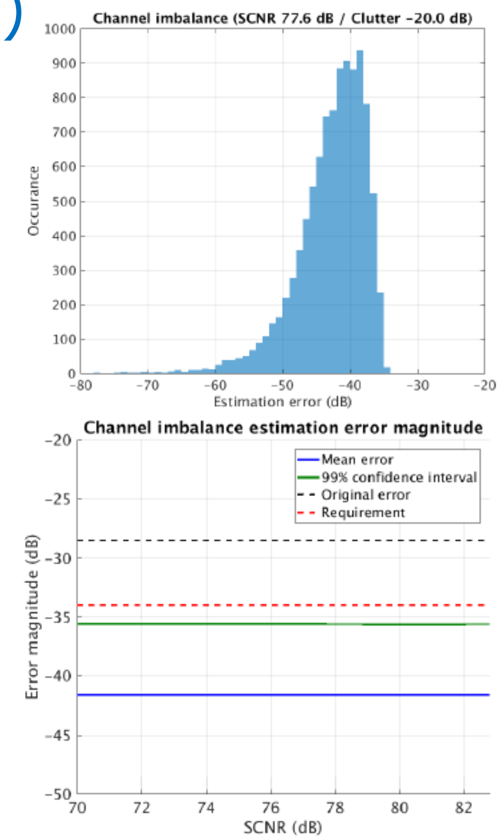
(b) Monte Carlo method.

Results (5000 runs)

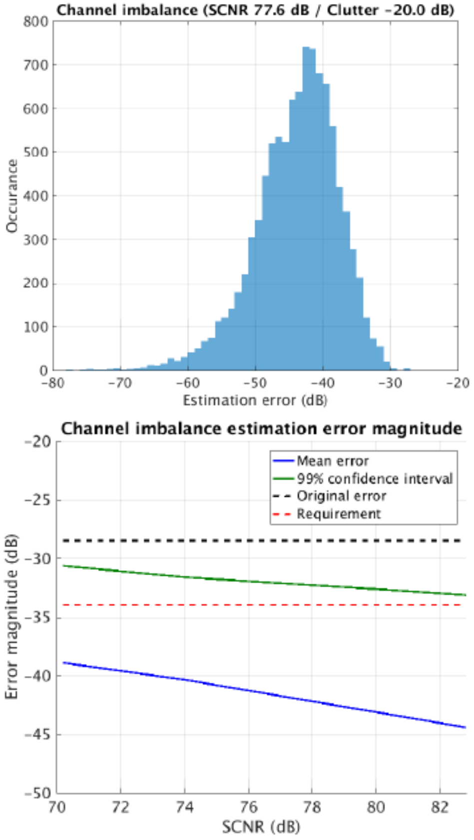
Channel imbalance estimation error

- Analytical method accurately estimates the CIs and is unaffected by noise and clutter. Bias due to the transponder has less of an effect on the channel imbalance solution

- Monte Carlo method has more difficulty and cannot give the required accuracy for the CIs. The solution improves with SCNR but it needs to be unattainably high in order to be accurate enough



(a) Analytical method.



(b) Monte Carlo method.

BIOMASS Transponder Development

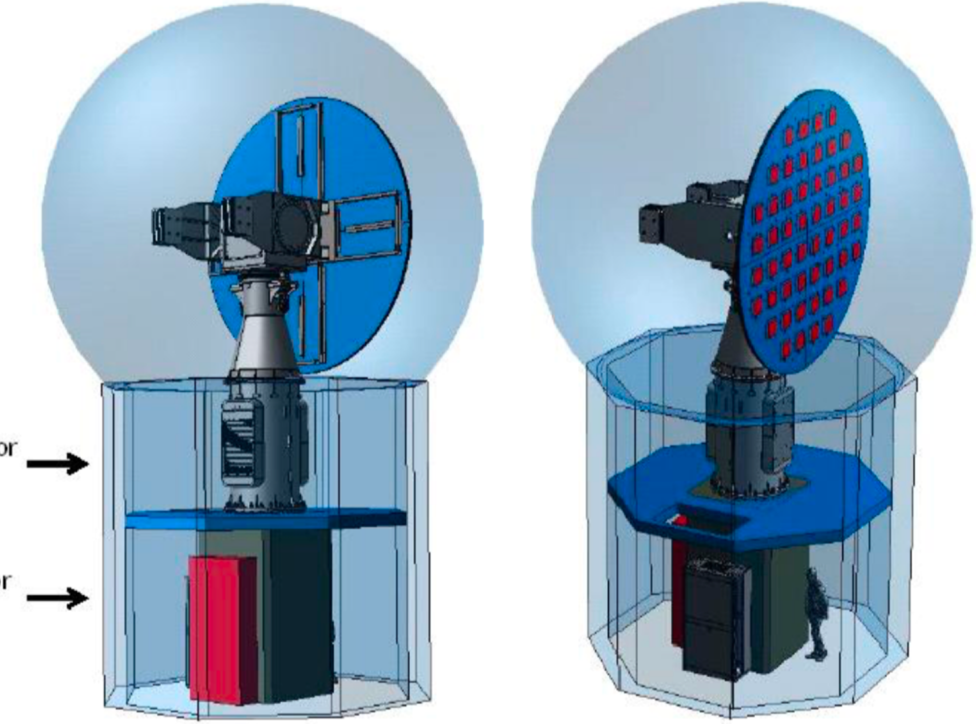
Activity led by C-CORE

Currently in design phase

Single antenna transponder (as with ESA S-1 Transponders)

→ High sidelobe suppression required to control Signal-to-Multipath Ratio (SMR)

→ Tracking required: to achieve the required cross-polar isolation (considered highest at the peak of the beam)

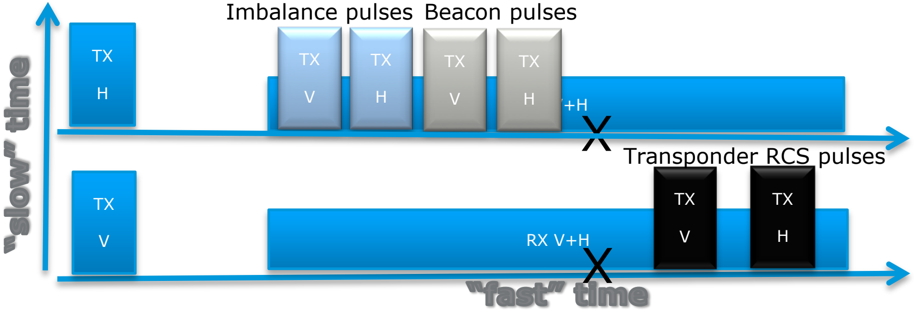


Targets emulation of the PARC

Targets to be emulated by the PARC:
(scattering matrix)

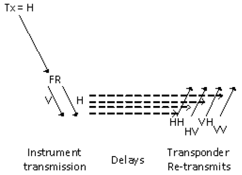
$$S^{HH} = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}, \quad S^{VV} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}, \quad S^{HV} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}, \quad S^{VH} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$$

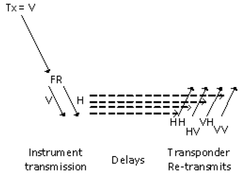
1 2 3 4

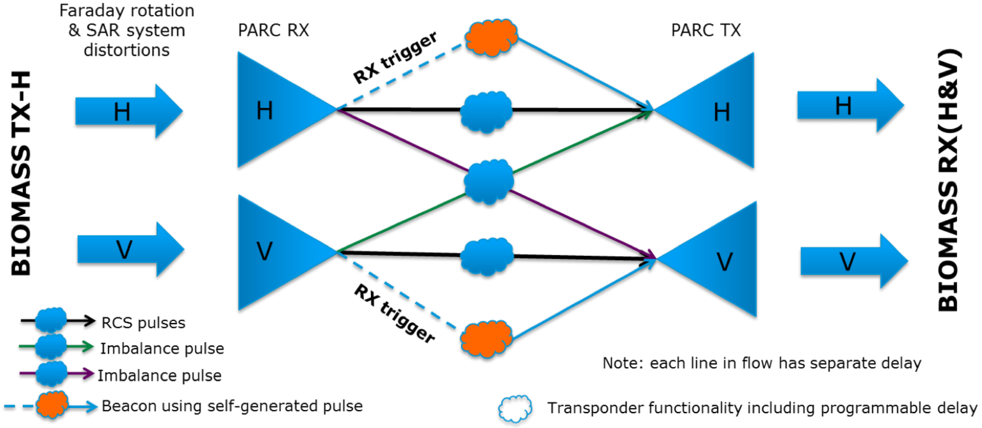


Signals to be transmitted by the PARC:

Target	TX - SAR	RX -PARC	TX -PARC
1	H	H	H
	V	H	H
2	H	V	V
	V	V	V
3	H	H	V
	V	H	V
4	H	V	H
	V	V	H







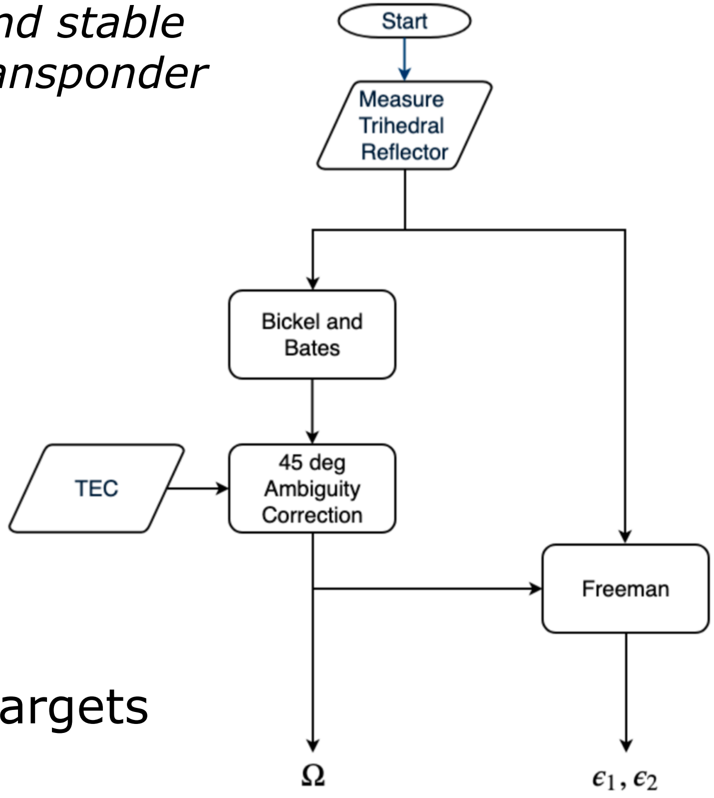
Recalibration/ monitoring using opportunistic targets

Assumption: cross-talk levels are sufficiently known and stable
→ After commissioning phase (dedicated cal orbit), transponder contact is limited

$$\mathbf{M} = \begin{bmatrix} 1 & 0 \\ 0 & f_1 \end{bmatrix} \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \mathbf{S} \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & f_2 \end{bmatrix}$$

Target characterization:

$$\mathbf{S} = \begin{bmatrix} 1 & \gamma_{VH} \\ \gamma_{HV} & 1 \end{bmatrix}$$



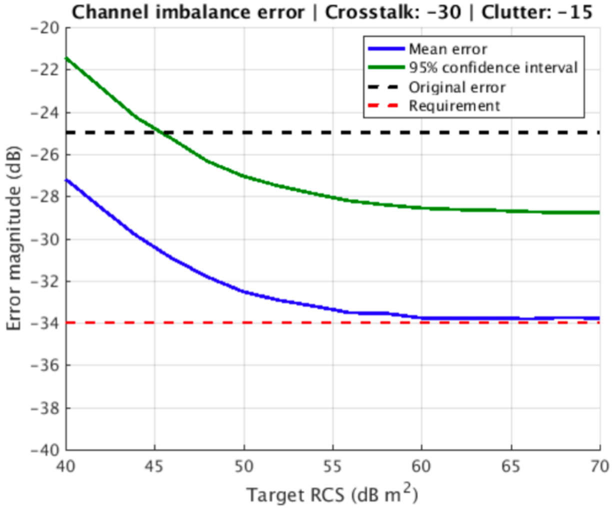
- 95% confidence level used for opportunistic targets

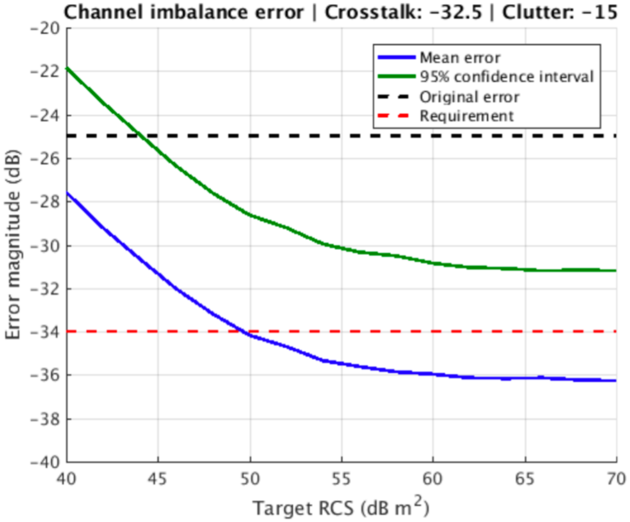
Recalibration/ monitoring using opportunistic targets

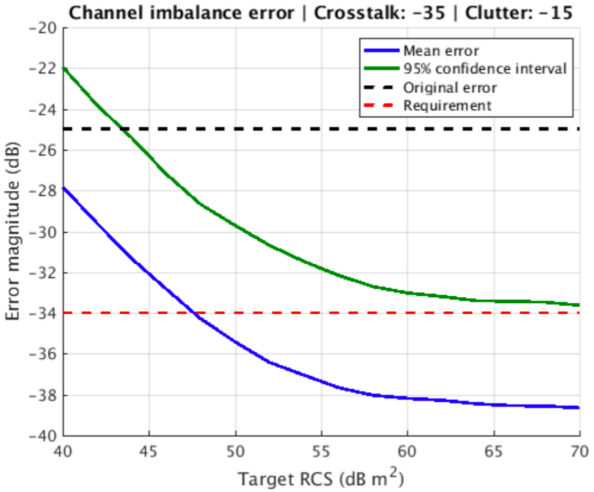
Depending on the achieved cross-talk & local clutter levels, targets with RCS in the range 50 – 60 dBm^2 may still proof useful

→ corresponding to trihedral between 10 and 18.5 m side edges

→ or …





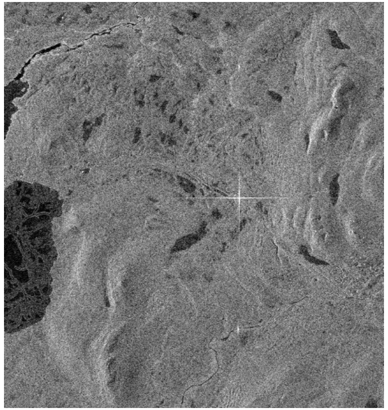


Use of Radiotelescopes for BIOMASS

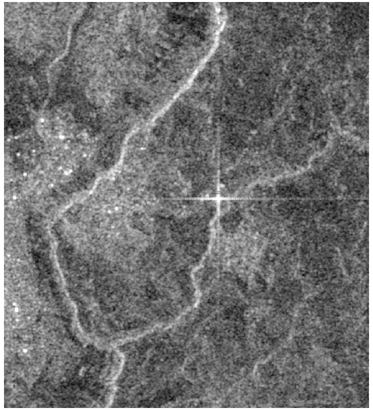
Investigated targets using Sentinel-1

- Radiotelescopes and downlink stations (Spring 2011 with ERS-2 and Envisat)
- Matera and Kiruna response clipped in Sentinel-1 SLC data
  - PDGS ensures DLR transponders (~61 dBm^2) within dynamical range
  - Solution: reprocessing of datasets
- Orgov ROT54 is not saturated in Sentinel-1

Matera



Kiruna



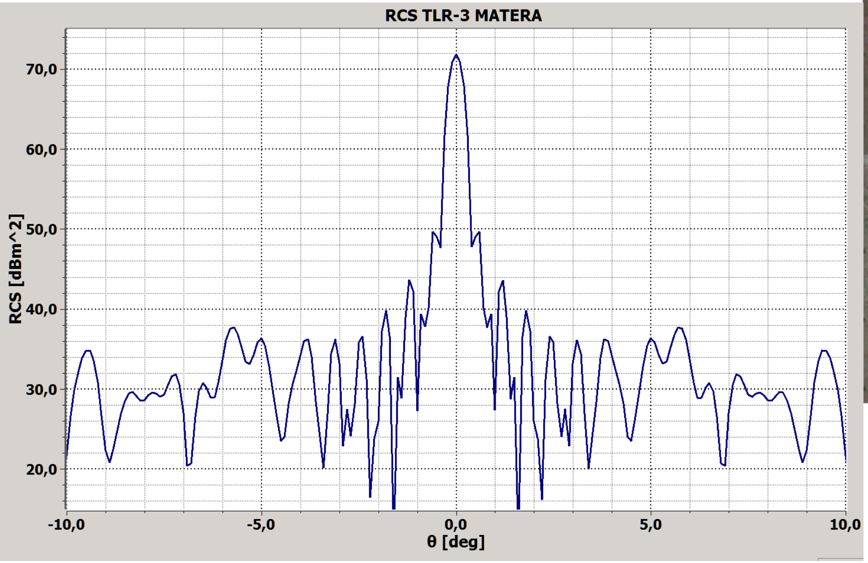
Orgov

Matera ground stations investigated with S-1

RCS modelling assumptions

- X-band feed only; disc approximation
- Cassegrain with no shaping

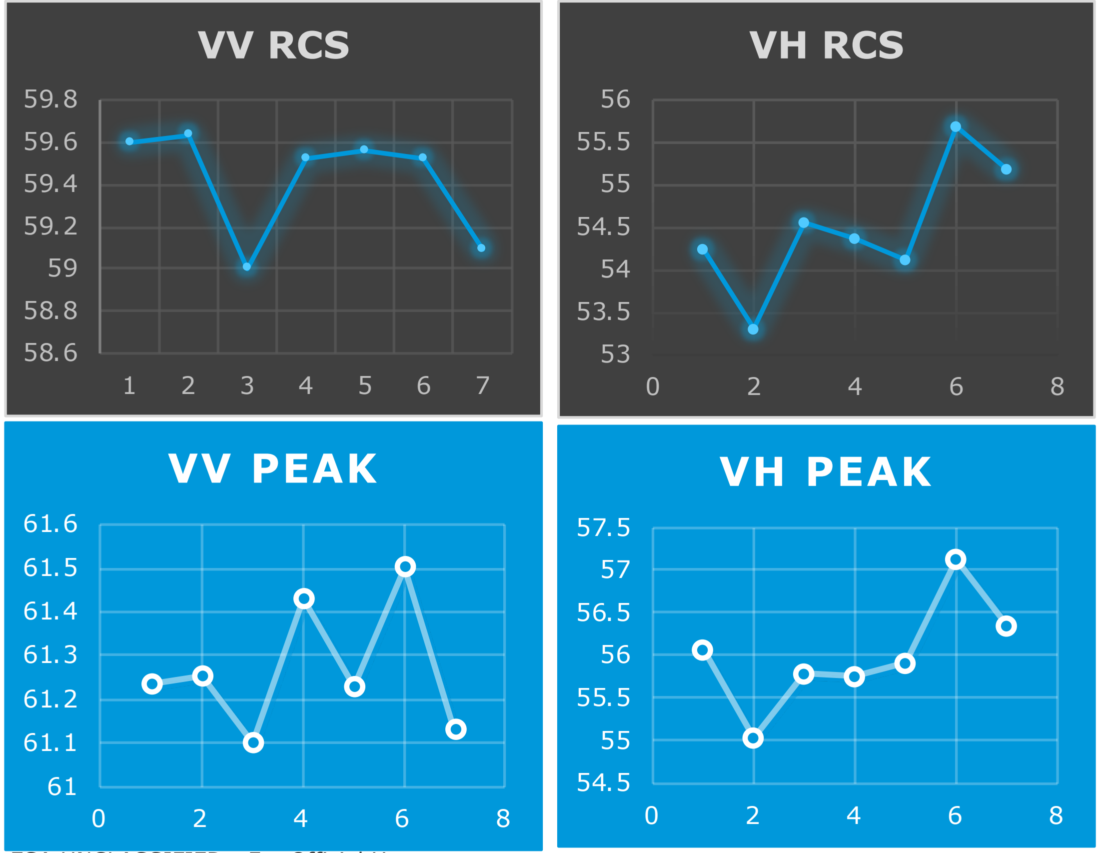
- Peak RCS @ C-band 71.7 dBm^2
- RCS @ P-band < 50 dBm^2



10 meter antenna "TLR-3"

11.3 m antenna "TLR-6"

Orgov @ C-band



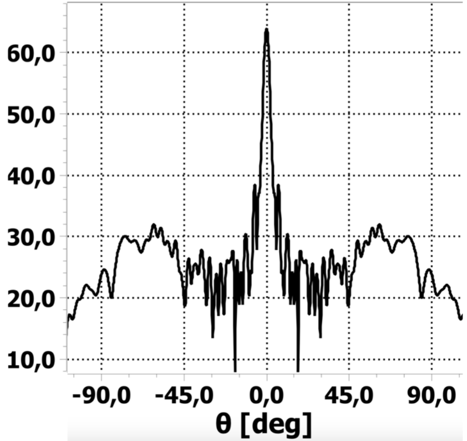
- 7 products equi-spaced 12 days and with the same observing geometry
- Orgov RCS stability 0.6 dB for VV and 2.3 dB for VH (peak-to-peak values)
- For peak method → in 0.4 dB for VV and 2.1 dB for VH
- Orgov is a complex target to precisely model (feed structure), but very stable in VV and consistent target during Sentinel-1 life time
- Due to low RCS and polarimetric properties not recommended for BIOMASS monitoring

S1B_IW_SLC__1SDV_20190902T030820_20190902T030847
S1B_IW_SLC__1SDV_20190914T030821_20190914T030848
S1B_IW_SLC__1SDV_20190926T030821_20190926T030848
S1B_IW_SLC__1SDV_20191008T030822_20191008T030848
S1B_IW_SLC__1SDV_20191020T030822_20191020T030849
S1B_IW_SLC__1SDV_20191101T030821_20191101T030848
S1B_IW_SLC__1SDV_20191113T030822_20191113T030849

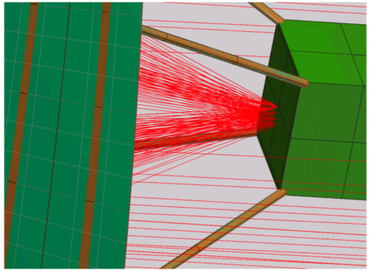
Other targets RCS @P-band

ALMA, Chile
54 @12m Ø
12 @ 7m Ø

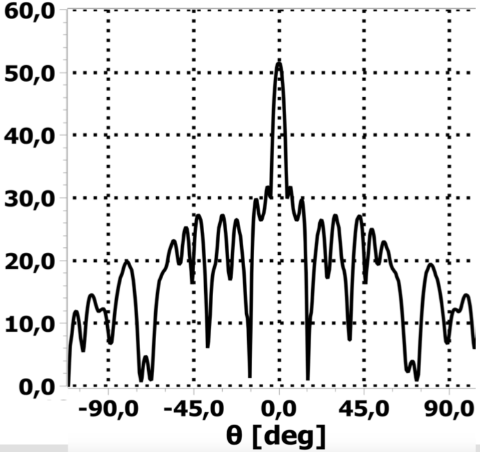
→ 51.5 dBm²

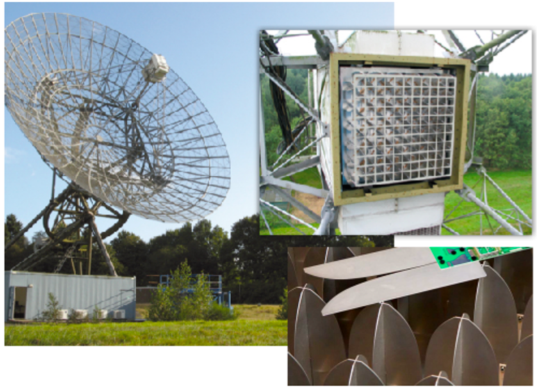


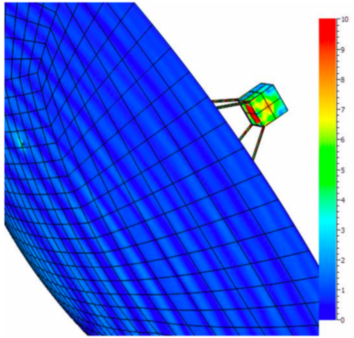
Westerbork, NL
14 @25m Ø



Atacama desert
5000 m a.s.l.







Next steps

BEEPS / Biomass end-to-end performance simulator

→ implementation and performance tests of polarimetric calibration approaches

Opportunistic targets investigation using Sentinel-1

→ use of ground stations & radio-telescopes

→ including accurate modelling of these targets

What about distributed targets for calibration purposes?

→ suitability of ocean surfaces, plateau regions (deserts, ice sheets)

→ use of distributed targets in nominal mission phases