Distributed SAR by formation flying CubeSats in a long-baseline bistatic scenario

Multistatic Radar Workshop 2025

Milan, June 19

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

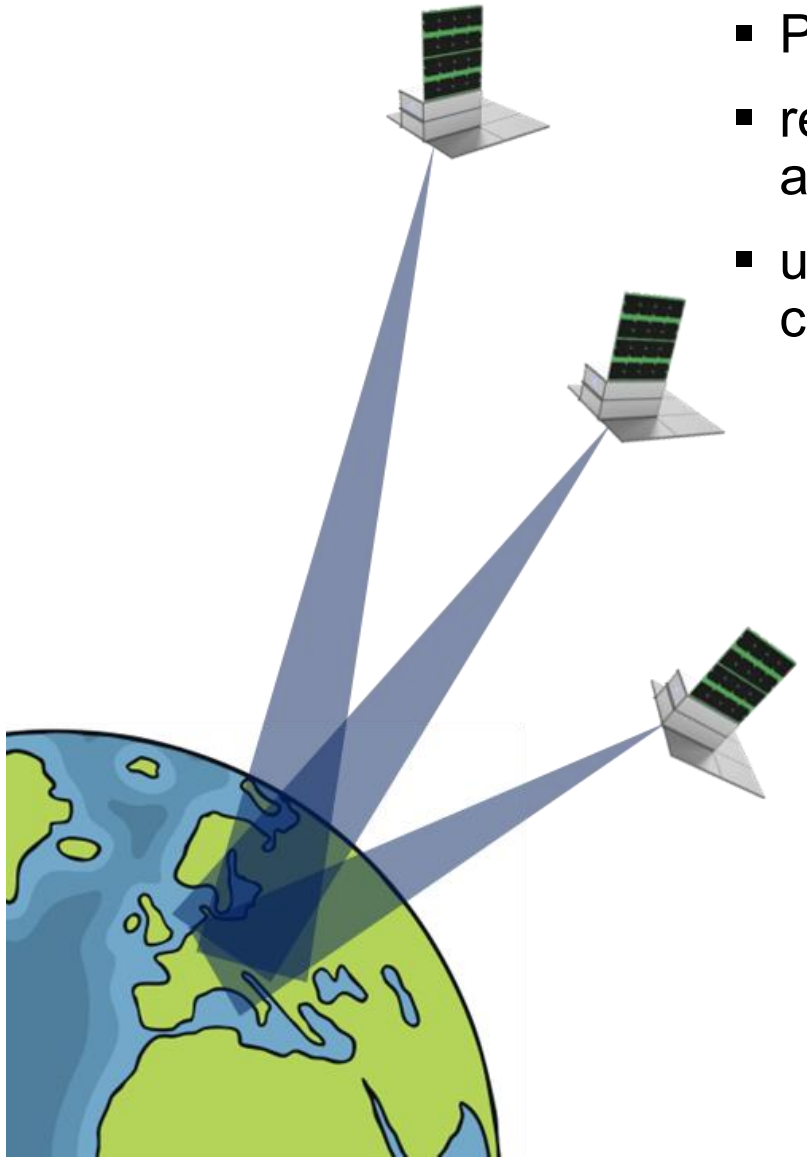
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

UNINA AEROSPACE SYSTEMS

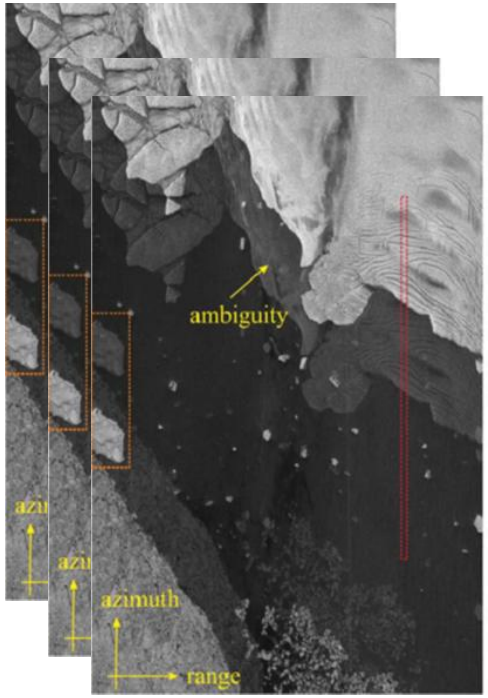
Outline

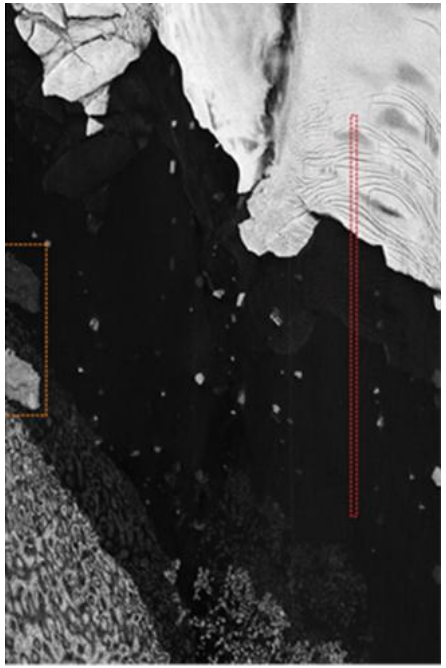
- Distributed SAR
  - DSAR and CubeSats
  - Long-baseline bistatic acquisitions
- RODiO as an IOD SAR mission
  - Satellite Design
  - Mission Analysis

Distributed SAR (DSAR) - an example



- PRF lower than Nyquist rate to achieve wide-swath imaging
- receivers operating on different satellites that observe the same area with an along-track separation
- unambiguous signal reconstruction in post processing by coherent combination of the raw data collected by each satellite



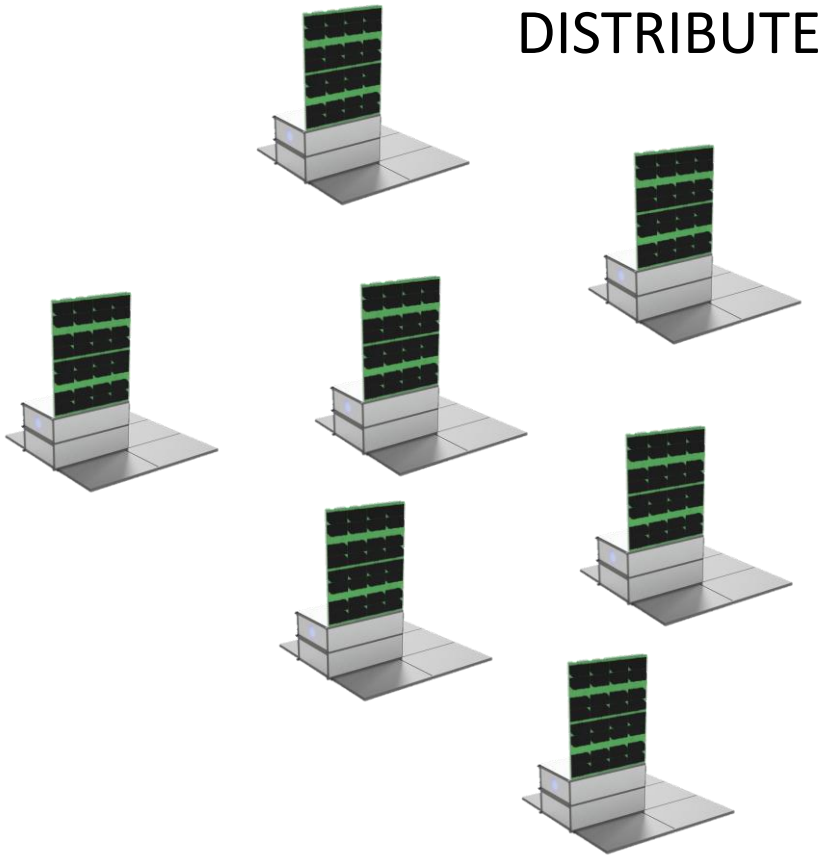


T. Kraus, G. Krieger, M. Bachmann and A. Moreira, "Spaceborne Demonstration of Distributed SAR Imaging With TerraSAR-X and TanDEM-X," in IEEE Geoscience and Remote Sensing Letters, vol. 16, no. 11, pp. 1731-1735, Nov. 2019, doi: 10.1109/LGRS.2019.2907371.

DSAR and CubeSats

MONOLITHIC

DISTRIBUTED



CubeSats as expendable and disposable items

? Reduced costs

? Increased flexibility

? Gentle degradation

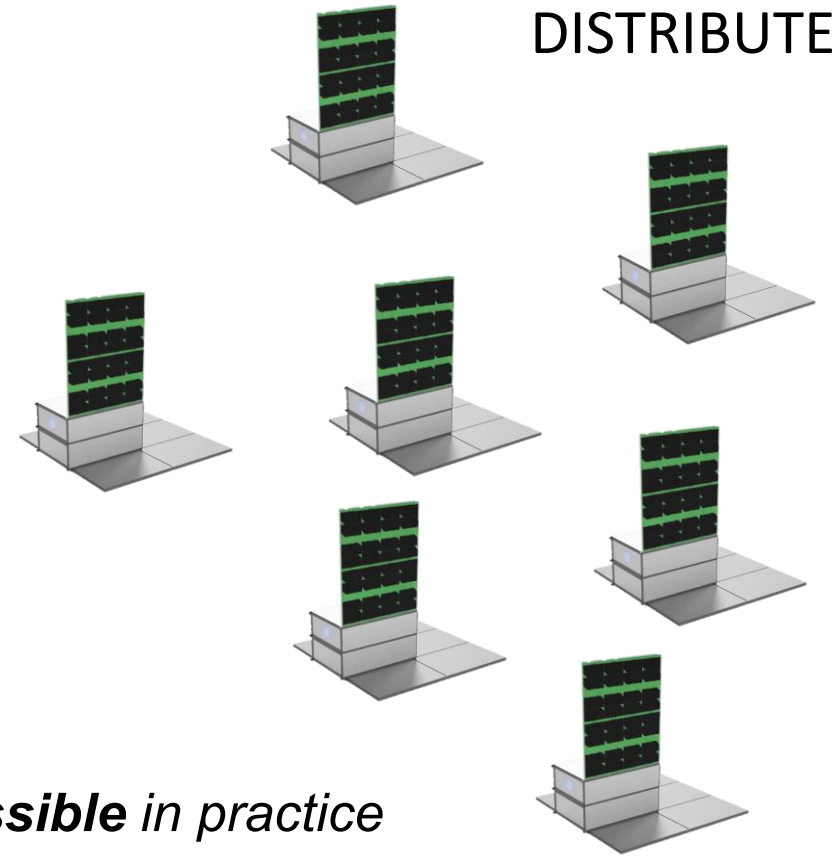
? Easier replacement

DSAR and CubeSats

MONOLITHIC

≠

DISTRIBUTED



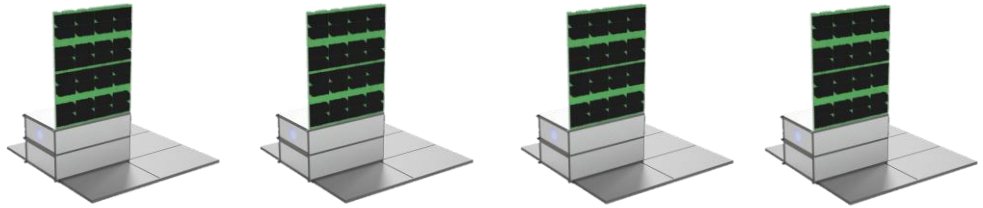
*Equivalence can easily become **not possible** in practice*

DSAR and CubeSats

MONOLITHIC

≈

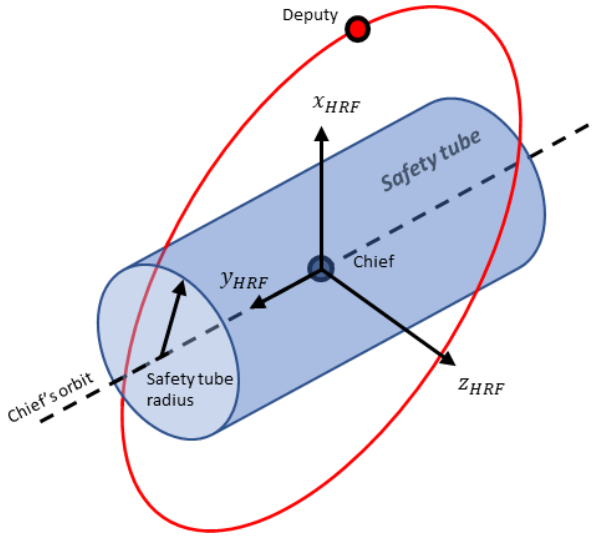
DISTRIBUTED

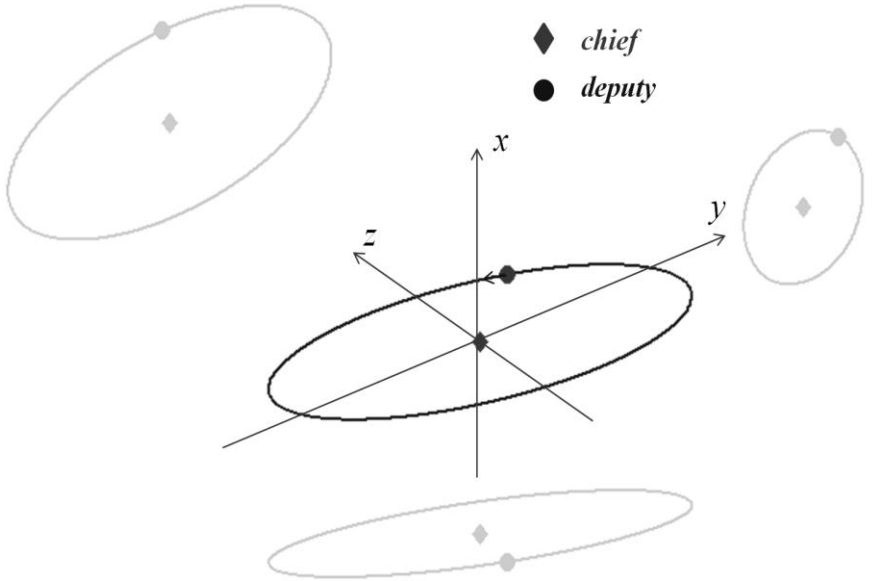


- ✓ along-track formation
- ✓ no further baseline component
- ✓ capability to control the along-track baseline with accuracy << then V/PRF, i.e. dm scale

DSAR by CubeSats: practical considerations on relative orbits

- Additional baseline components may be helpful to make the formation safer
  - Formation flying by platforms with limited authority of control





- ✕ sensitivity to topography
- ✕ loss of coherence
- ✕ loss of control of relative arrangements among the collected samples
- ✕ more complex processing since topography compensation is mandatory

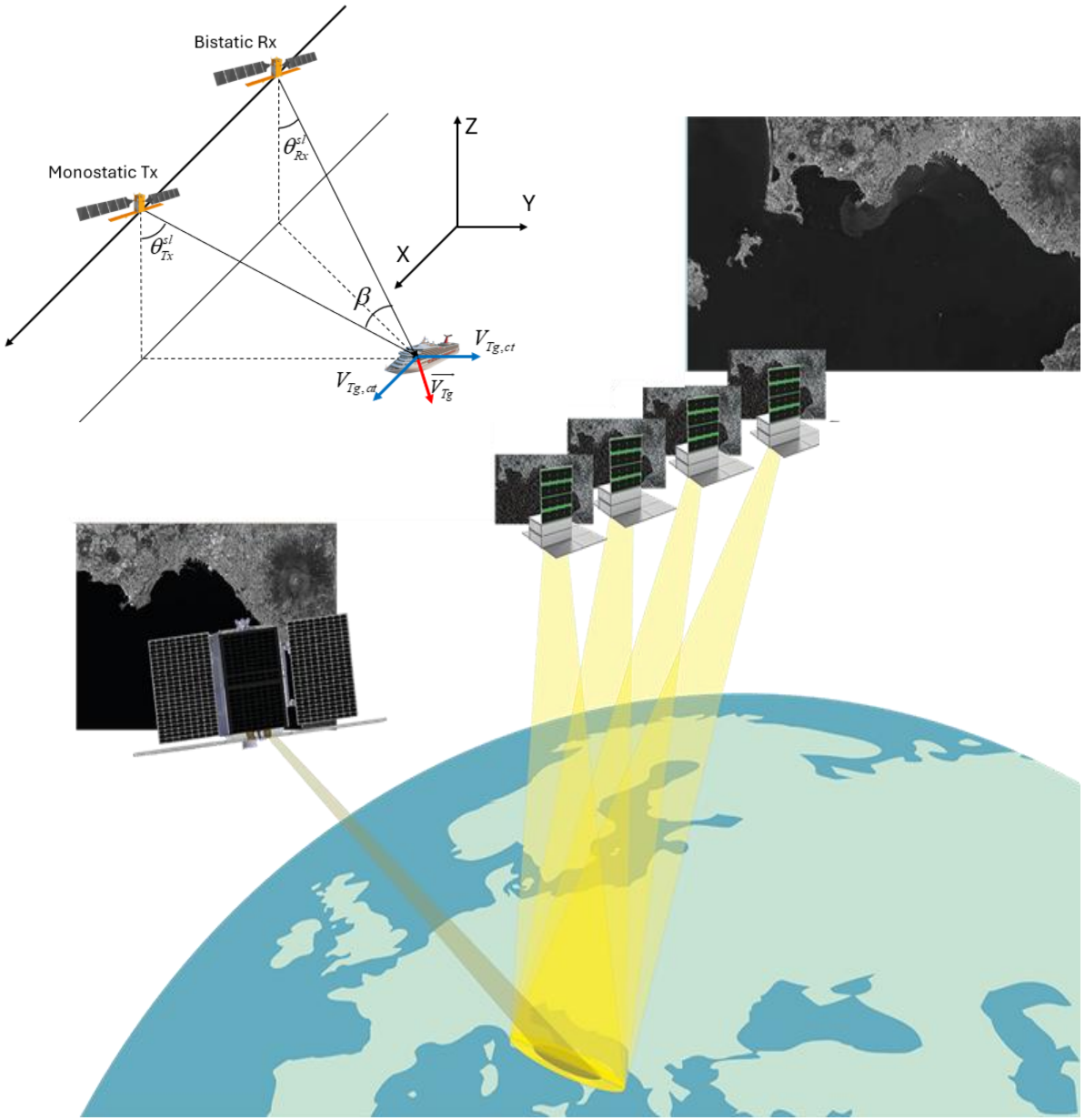
Redundancy (more CubeSats) as a way to make the relationship between DSAR performance and relative arrangement among the receiver less tightly coupled

… in a long-baseline scenario

- low SWAP (Size Weight And Power) features in CubeSats make the use of an illuminator of opportunity a valid alternative

- DSAR as a single bistatic companion in a long-baseline bistatic geometry wrt the transmitter

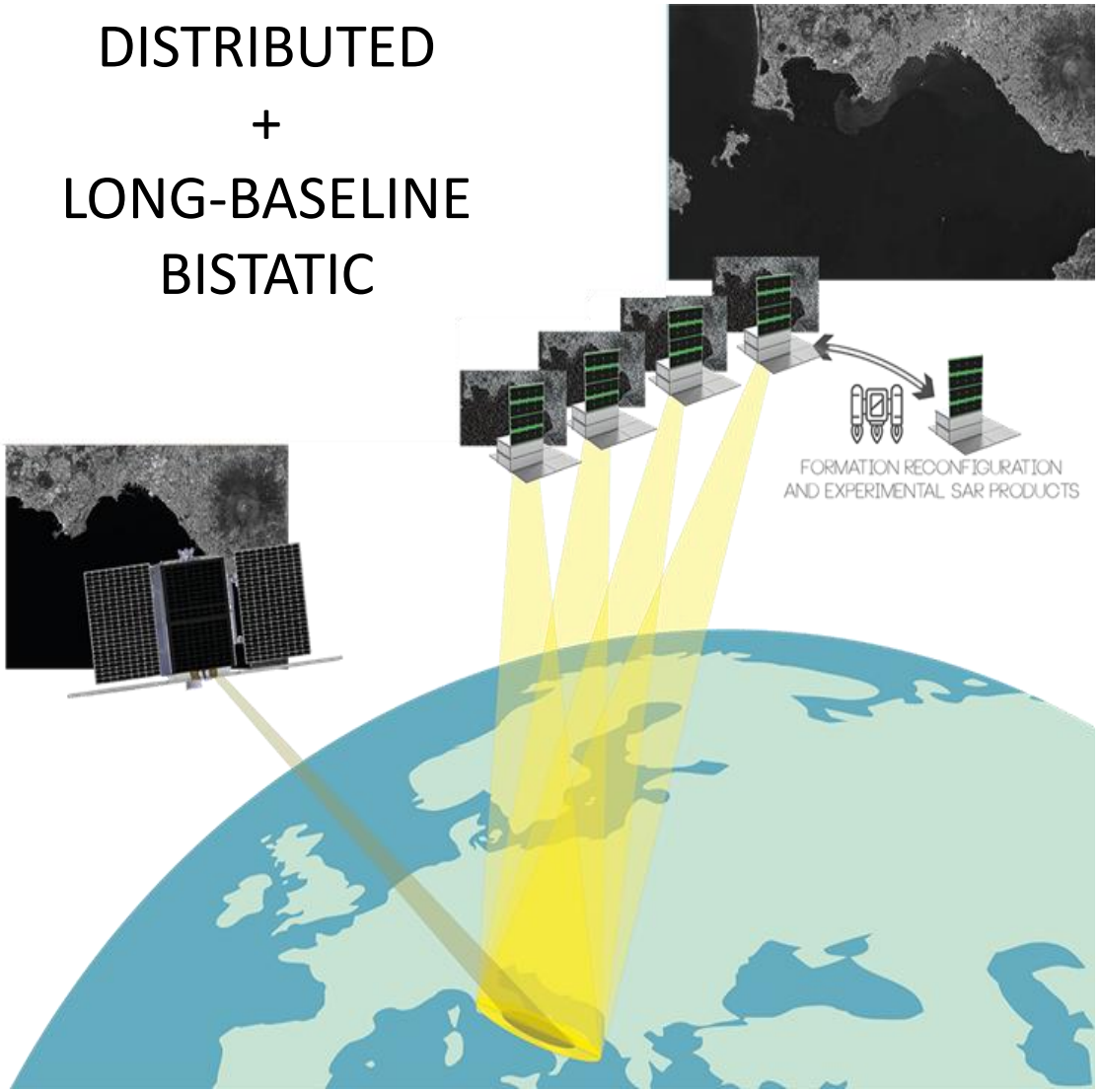
- **from a technological demonstration** to a system able to work with large bistatic angles, i.e. **demonstration of science and applications**
  - *bistatic scattering and polarimetry*
  - *ground motion*
  - *moving targets*
  - *radargrammetry*



Distributed SAR by formation flying CubeSats in a long-baseline bistatic scenario

MONOLITHIC

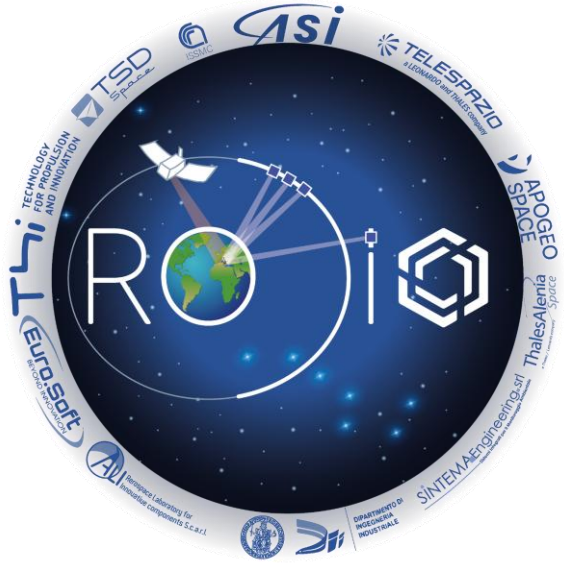
DISTRIBUTED
+
LONG-BASELINE
BISTATIC



- No general answer to conflicting aspects
- Lack of in-orbit experience

RODiO a DSAR IOD mission

- RODiO mission **empowers** ASI PLATiNO-1 (PLT-1) scopes and application fields
- RODiO is a cluster of 4 16U CubeSats **flying in formation among them and with** PLT-1 at about 428 km altitude
- Each CubeSat embarks a **receiving-only X-band SAR** instrument able to collect bistatic echoes exploiting PLT-1 as an opportunity illuminator
- One CubeSat is provided with a flight demonstrator of an innovative **hybrid rocket propulsion** unit



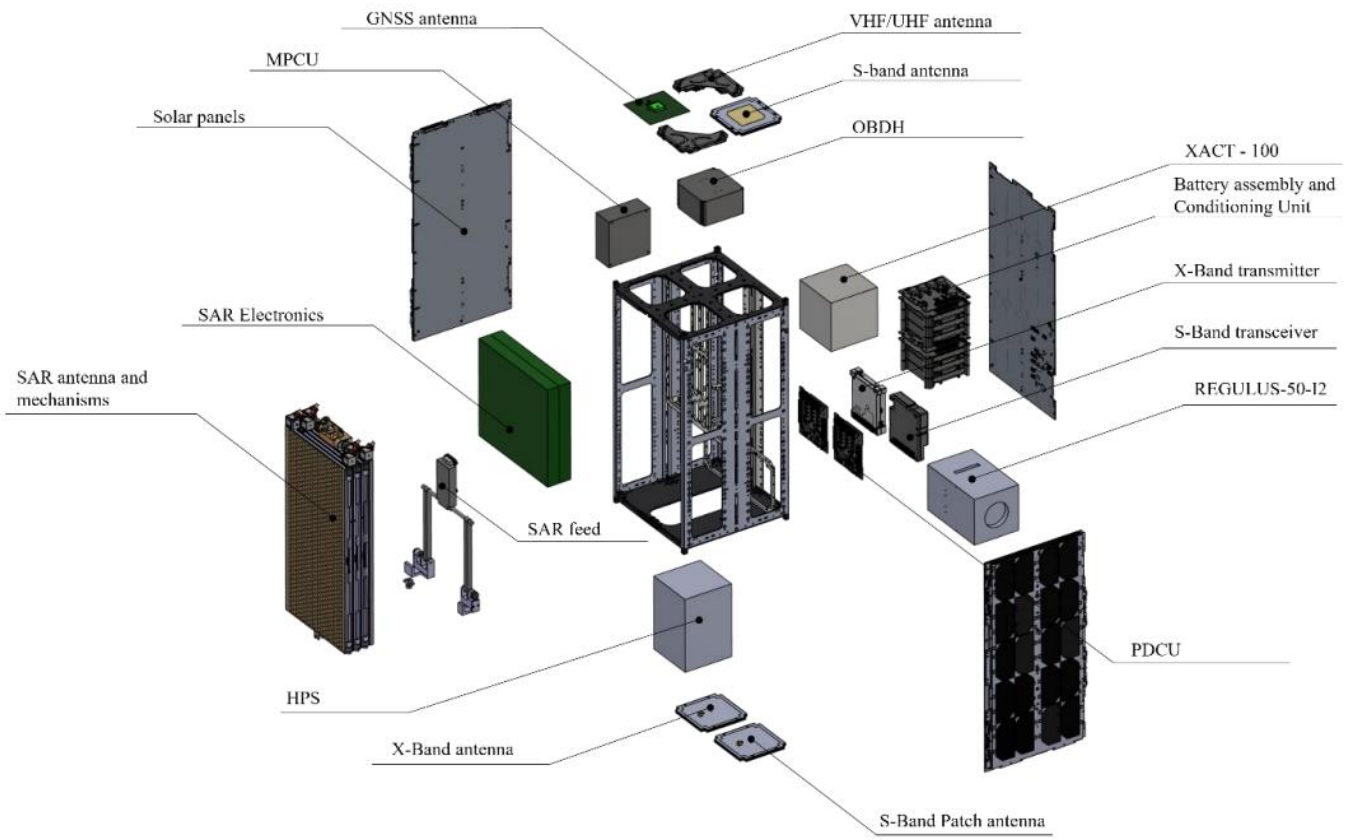
Phase A: Concluded

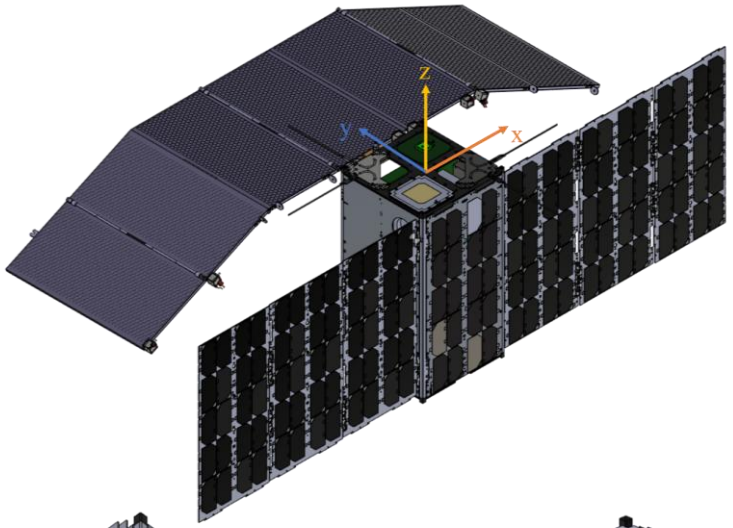
	1 CubeSat	4 CubeSats
Resolution	5 m x 5 m	5 m x 5 m
NESZ	< - 9 dB	< - 13 dB
ASR	< - 5 dB	< - 15 dB

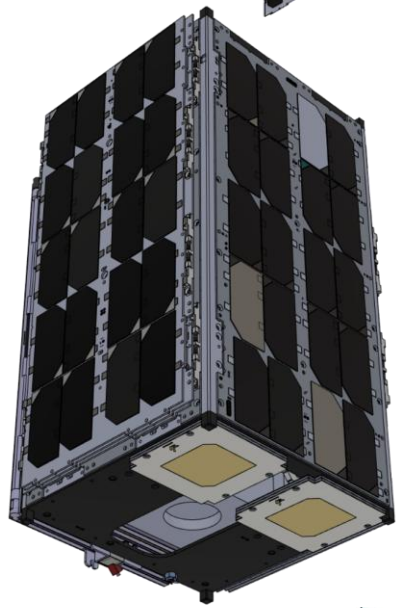
Phase B: Approved

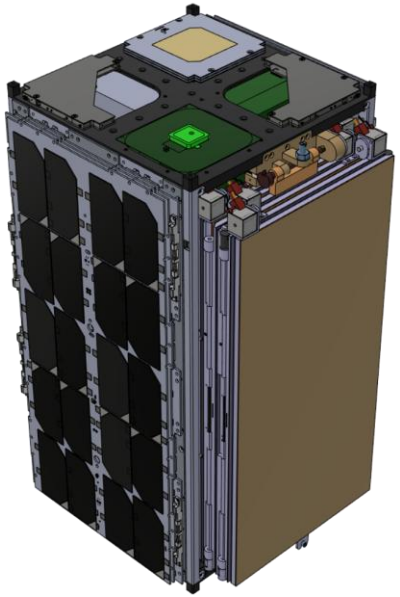
Along-track distance from PLT-1	50-90 km
Along-track cluster size	< 600 m
Cluster orthogonal baseline	< 200 m

Preliminary Satellite Design









- 16 U CubeSat with mass and volume compliant with Cubesat deployer
  - About 35 kg margined wet mass
  - maximum protrusion from the rails smaller than 39 mm

APOGEO SPACE

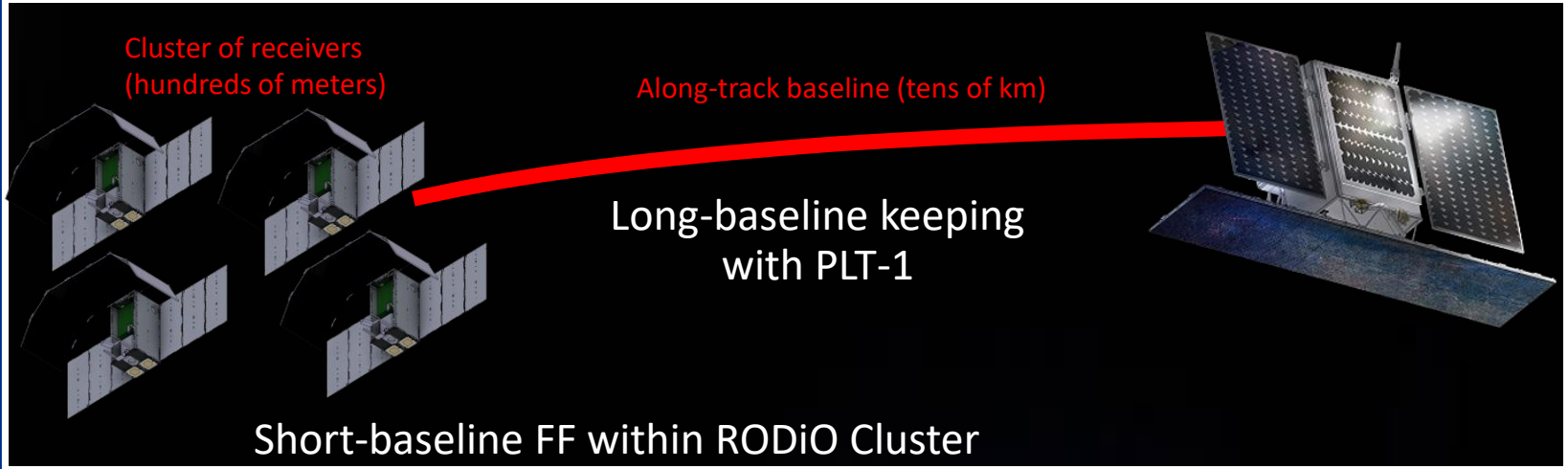
Mission Analysis and Formation Flying

Launch, deployment, and formation acquisition

- Shared launch
- Carrier, such as D-Orbit ION-mk03, used for orbit acquisition
- Acquisition of the final formation relies on Regulus by T4i

Maintenance Maneuvers to be applied on two levels:

- Long-Baseline Keeping ➔To maintain the along-track separation wrt PLT-1
- Formation Maintenance ➔ To maintain the cluster geometry



Vertical and cross-track separations together with significant along-track drift wrt PLT-1 allowed and managed within DSAR image generation

1-year mission enabled by less than 70 m/s deltaV

1224 • 2024
ad scientiarum haustum

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

MUR DII Dipartimento di Eccellenza 2023 - 2027

Thank you for the attention

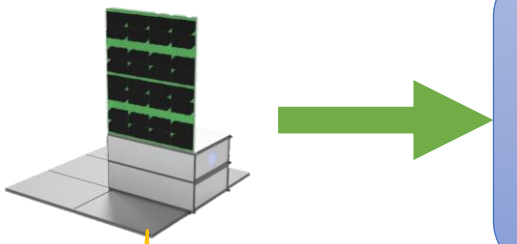
UNINA DSAR GROUP

Alfredo Renga	*Technical and Scientific Responsible*
Maria Daniela Graziano	*Project Manager*
Antonio Gigantino	*DSAR performance and processing*
Francesca Pelliccia	*Relative Positioning*
Maria Salvato	*Formation Flying*
Gianluca Coppa	*Data-driven Synchronization*

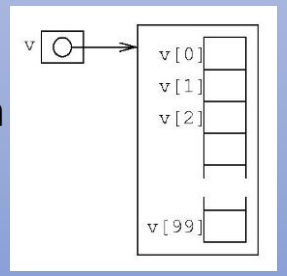
SPACE IT UP!

alfredo.renga@unina.it

Synchronization Scheme



Raw data vector



PRF estimation based on autocorrelation function

Raw data matrix

Compensated raw data matrix

Multi-platform image synthesis

Bistatic image focusing

Stationary Phase Error estimation and correction based on autofocus algorithms

Frequency drift estimation

Individuation of tie point among bistatic images

Absolute time offset estimation

Individuation of tie point with respect to the monostatic reference image

Selection of ground control points