Future Copernicus SAR Missions

Overview on Status and Companion Friendliness

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ROSE-L and S1NG Project teams

Copernicus Timeline – Current and Future SAR Missions

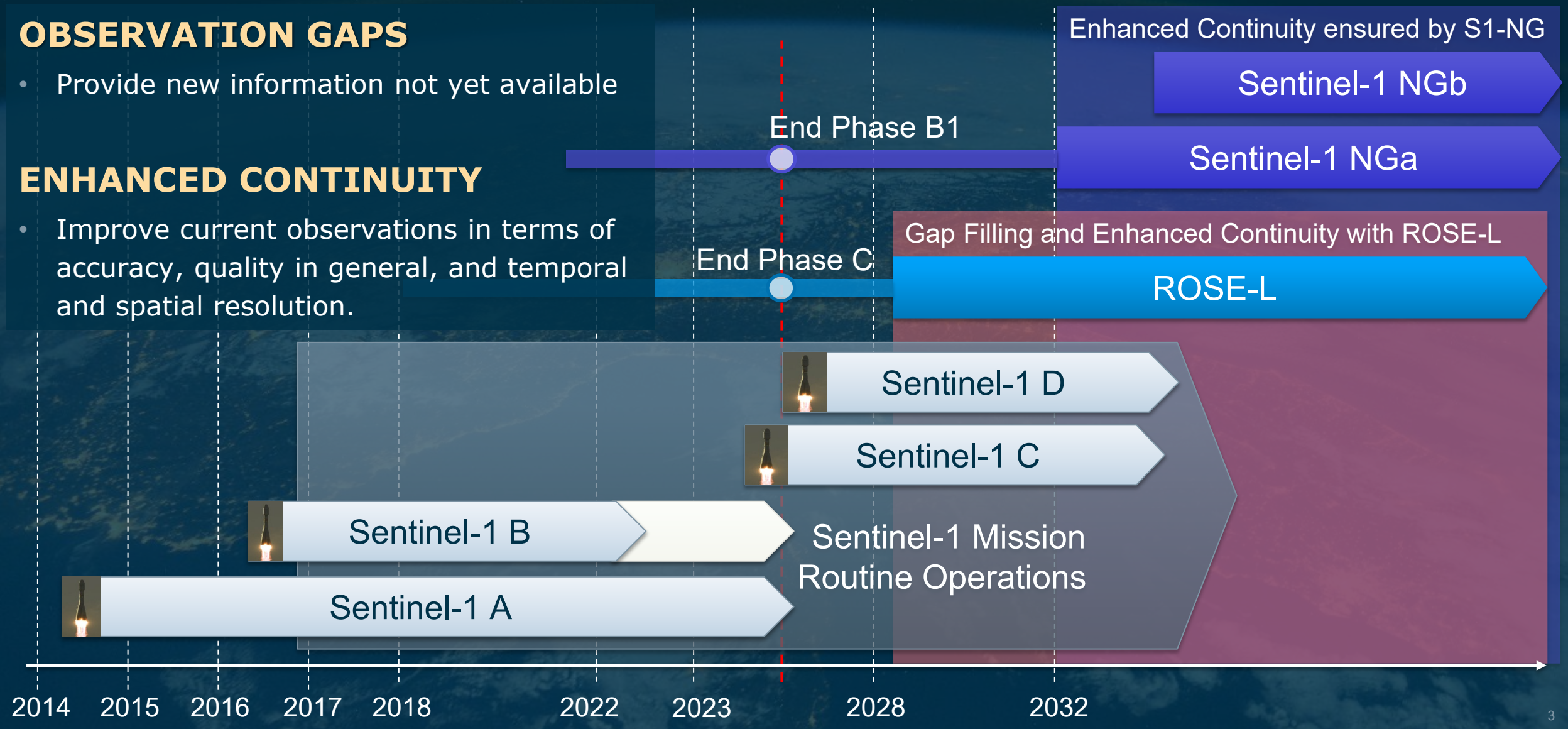
Expansion Mission Objectives

OBSERVATION GAPS

- Provide new information not yet available

ENHANCED CONTINUITY

- Improve current observations in terms of accuracy, quality in general, and temporal and spatial resolution.



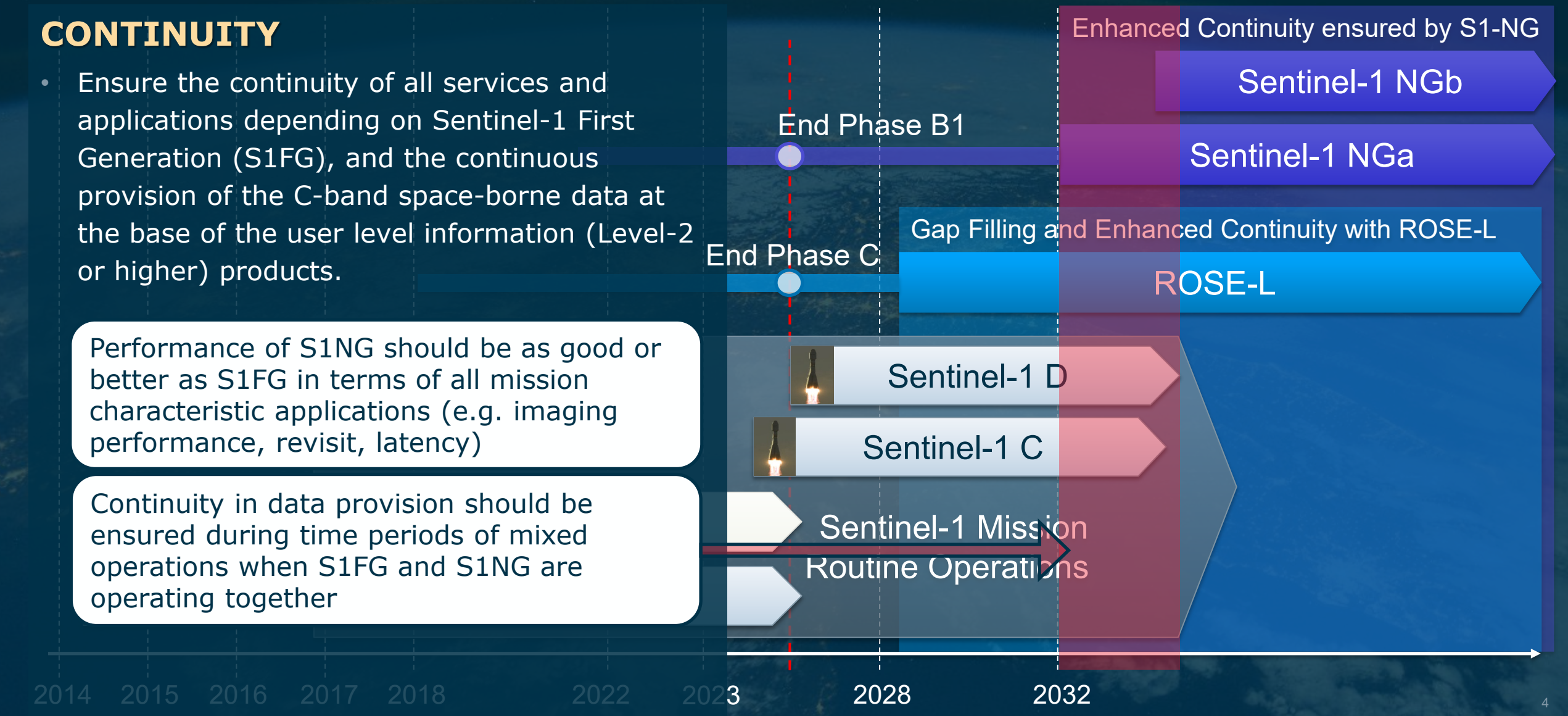
Sentinel-1 Next Generation Objectives

CONTINUITY

- Ensure the continuity of all services and applications depending on Sentinel-1 First Generation (S1FG), and the continuous provision of the C-band space-borne data at the base of the user level information (Level-2 or higher) products.

Performance of S1NG should be as good or better as S1FG in terms of all mission characteristic applications (e.g. imaging performance, revisit, latency)

Continuity in data provision should be ensured during time periods of mixed operations when S1FG and S1NG are operating together

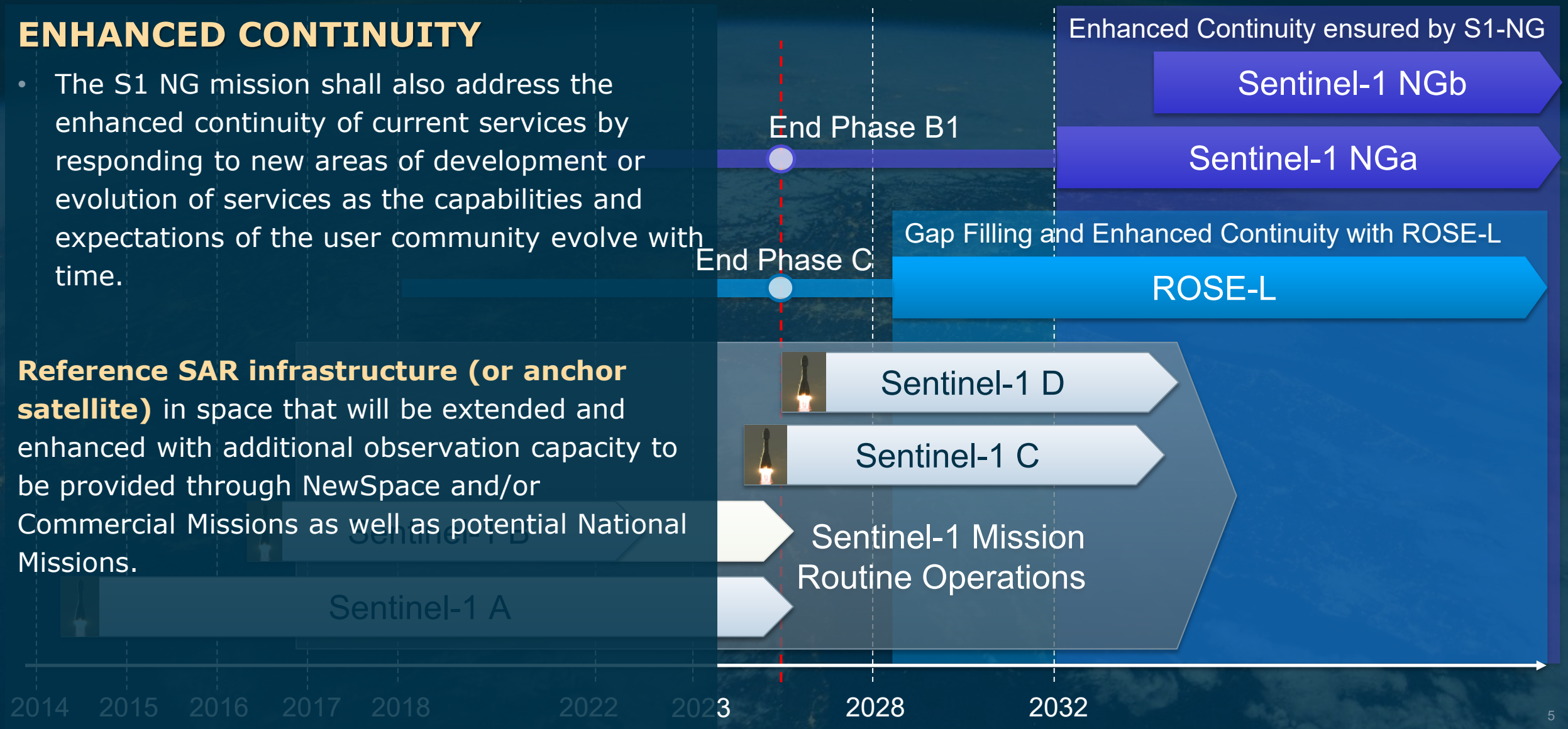


Sentinel-1 Next Generation Objectives

ENHANCED CONTINUITY

- The S1 NG mission shall also address the enhanced continuity of current services by responding to new areas of development or evolution of services as the capabilities and expectations of the user community evolve with time.

Reference SAR infrastructure (or anchor satellite) in space that will be extended and enhanced with additional observation capacity to be provided through NewSpace and/or Commercial Missions as well as potential National Missions.

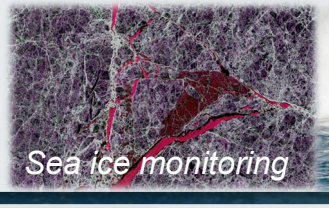


SAR Missions and Copernicus Services

C3S

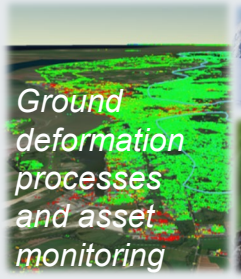
- Sea ice type, concentration and motion
- Ice sheets & glaciers velocity, grounding line
- Ground movement
- Snow water
- Ice sheet melt/freeze extent
- Permafrost thawing and extent

CMEMS



- Sea ice type, concentration and motion
- Iceberg location, size and drift
- Ocean surface wind vectors
- Swell properties
- Ocean surface currents

CLMS



- Land use and land use change, including agriculture and forestry
- Soil moisture
- Forest biomass and structure
- Snow water
- Wet snow extent
- Ground movement

EMS

- Flooded area
- Ground movement
- Soil moisture
- Abrupt surface elevation changes

Security

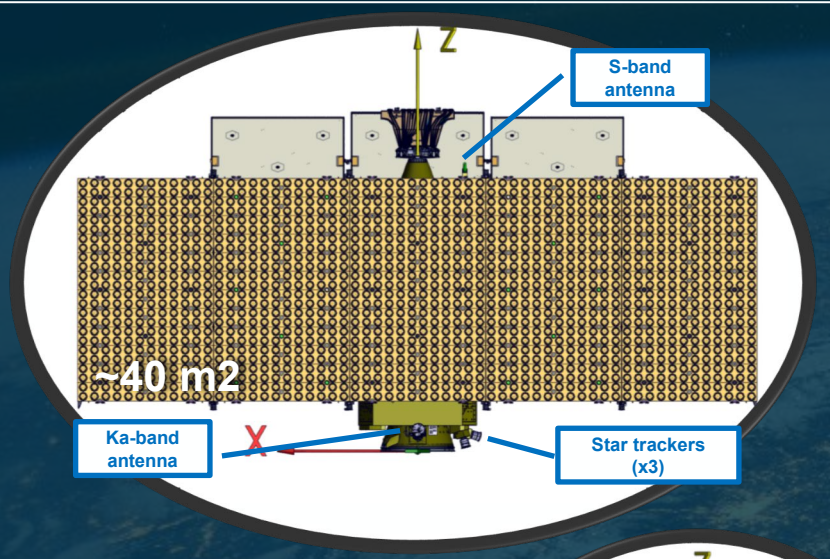
EMSA FRONTEX

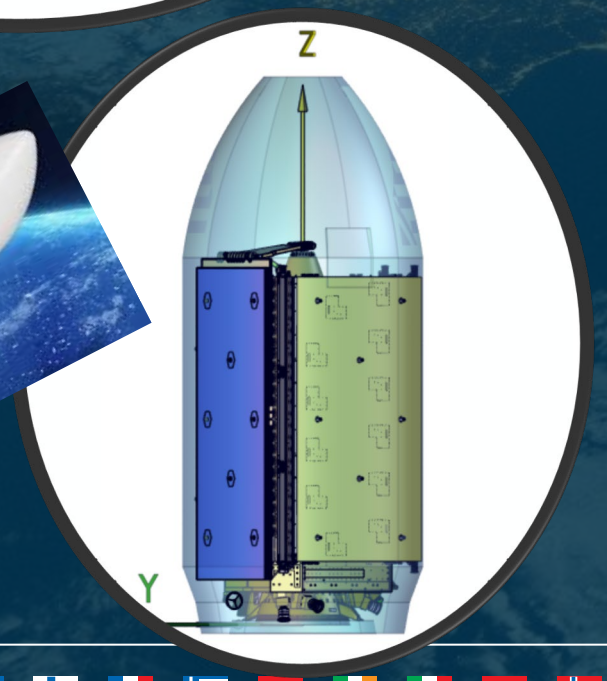
- Iceberg location, size and drift
- Vessel location, size and velocity
- Oil spill location and morphology

User Needs

- Polar Expert Group
- REDD+
- UNFCCC
- ….

ROSE-L Mission in Brief





GENERAL

- Consortium led by Thales Alenia Space Italy (TAS-I), involving 29 companies from 15 countries
- Constellation of 2 satellites (PFM & FM2)
- Design enhancing synergies with Sentinel-1: same orbit, co-located swaths

STATUS AND PROGRAMMATICS

- **Currently at the end of Phase C**
- System Critical Design Review (CDR) kicked off March 2025 and concluded successfully 4th June. Note that system CDR formally releases the manufacturing of flight HW
- MRD v3.0 released March 2025
- QAR of PFM expected in 2028

INSTRUMENT

- L-Band – 85 MHz ITU allocated band (1.215-1.300 GHz)
- Planar active array antenna of 11m x 3.6m
- SCORE in elevation
- MAPS in azimuth, 5 digital channels down-linked and combined on-ground

ROSE-L SAR Modes

ORBIT

- Same orbit of Sentinel-1 : Near polar sun-synchronous 693 km, 12 days repeat cycle

ROSE-L Interferometric Modes

	Dual-Pol (RIWS)	*Quad-Pol (QWS)*
Mode :	ScanSAR	ScanSAR
Access :	29° - 46° (*)	20° - 45° (**)
Swath :	260 km	260 km
Resol. (gr x az) :	5 m x 10 m	5 m x 20 m
NESZ :	< -28 dB	< -28 dB
DTAR :	< -23 dB	< -23 dB
Aux. Band:	up to 8 MHz	up to 8 MHz

* Full overlap with S1 IWS

** Fixed swath within such range, e.g. 25 ° - 42°

ROSE-L WAVE Mode

- Mode: Burst (ScanSAR-like)
- Access : Variable
- Swath : 20 km x 20 km vignettes (***)
- Resolution : 50 m^2
- NESZ : < -28 dB
- DTAR : < -23 dB

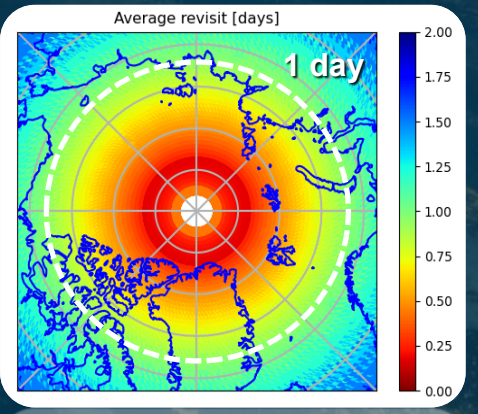
*** Vignette spacing TBC but 100km likely achievable

Optional SAR MODE (under study)

ROSE-L Extra Wide Swath Mode (REWS)

- Overlap with S1 EWS
- Swath : > 400 km
- Resolution : 20 (15) x 40 (35) m
- NESZ : < -30 dB

Access for 1 ROSE-L REWS



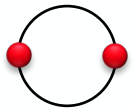
Global Coverage and Synergic Design with Sentinel-1

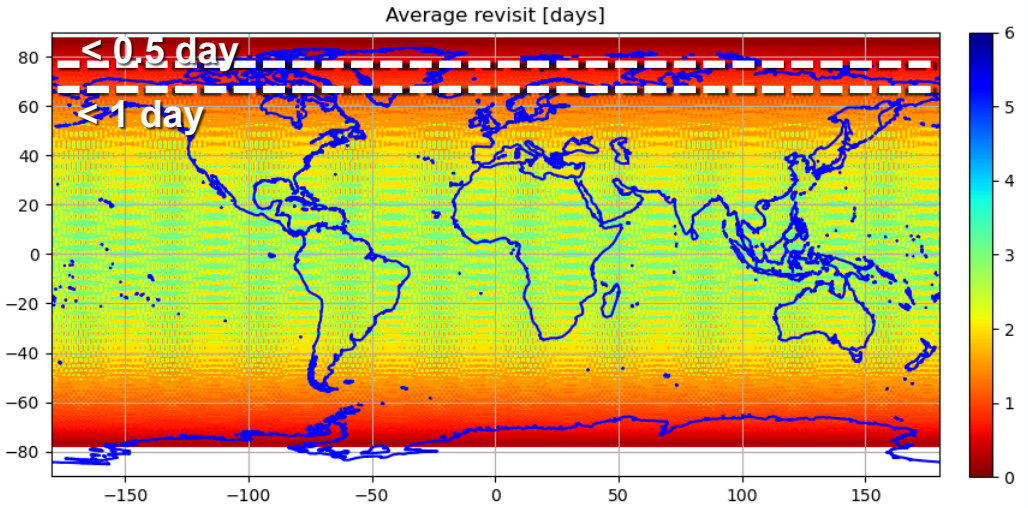
- Systematic acquisitions through years for **long-term coherent data stacks**
- Extensive Coverage of Global land (except for South pole). **~ 38 min/orbit duty cycle**
- **RIWS mode guarantees full swath overlap with S1 IWS**
- Mission design supports options for:
  1) convoy with Sentinel-1 (up to a minimum 1min baseline)
  2) different orbit phasing for optimized revisit

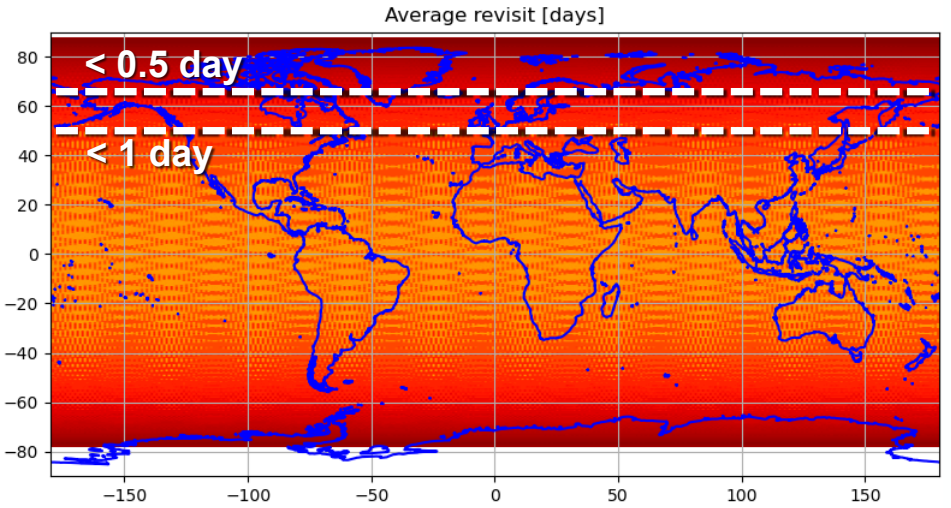
Requirement:
Revisit shall be less than
1 day (Arctic),
3 days (Europe),
6 days (Global)

ROSE-L

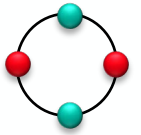
Phasing
3d - **9**d



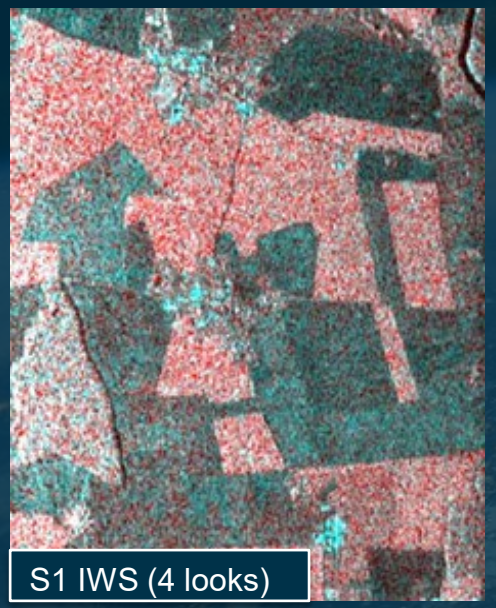




S1FG
+
ROSE-L



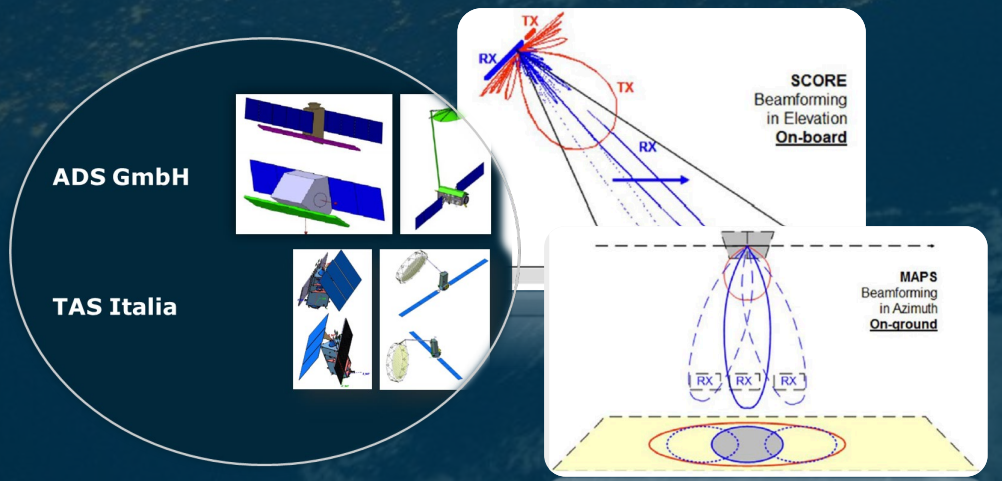
Sentinel-1 NG Mission in Brief


S1 IWS (4 looks)


S1 SM [~S1-NG] (4 looks)

MISSION AND SYSTEM REQUIREMENTS

- **Same orbit of S1FG / ROSE-L in constellation of two satellites**
- Performance shall be equal or better than Sentinel-1 FG
- Revisit: 3 days Global, 0.5 days Arctic and sea ice
- Resolution ≤ 25 m^2
- NESZ ≤ -26 dB
- Full continuity in Dual-Pol and Quad-Pol capability
- Use of a dedicated Mission Mode to cover the North Pole region
- Swath size ≥ 400 km



DEVELOPMENT STATUS AND SCHEDULE

- Phase A/B1: parallel studies with European industry (TASI and ADS GmbH)
  - Carried out over two years (2021-2023)
  - Instrument based on SCORE and MAPS
- Evaluation for Development Phase (B2/C/D/E1) ITT currently ongoing (TEB kicked-off Feb 2025)
- Expected S1NGa launch in 2034

Companion Friendliness

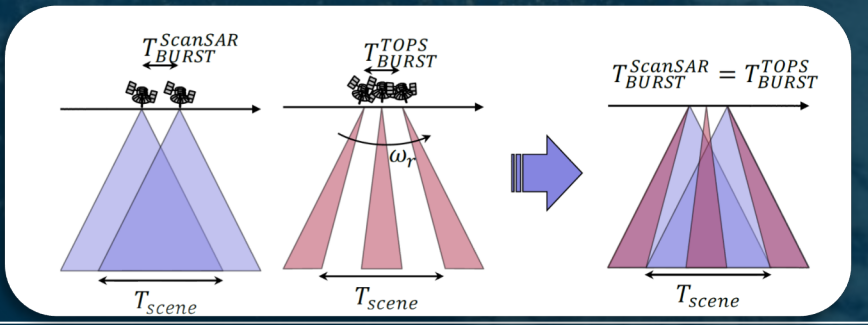
ROSE-L

- SAR formation mission concept abandoned after FM3 option expired at CDR
  - Option for Synch-link for phase synchronisation not exercised
  - References in MRD to objectives requiring XT or AT companion formation moved to cooperation section (not driving)
- ROSE-L system features still support potential operations with one or more additional companion satellites, albeit ‘best-effort’ companion design and performance to be considered

SENTINEL-1 NG

- Not driven by application objectives requiring mission companions.
- Companion friendliness with NewSpace missions analysed as Task
- Capability to provide USO phase as reference to GNSS receiver
- SAR Legacy mode option to be used during the S1NG Commissioning for S1FG / S1NG Cross-calibration and demonstration of Level-2 full continuity; also providing compatibility with Harmony

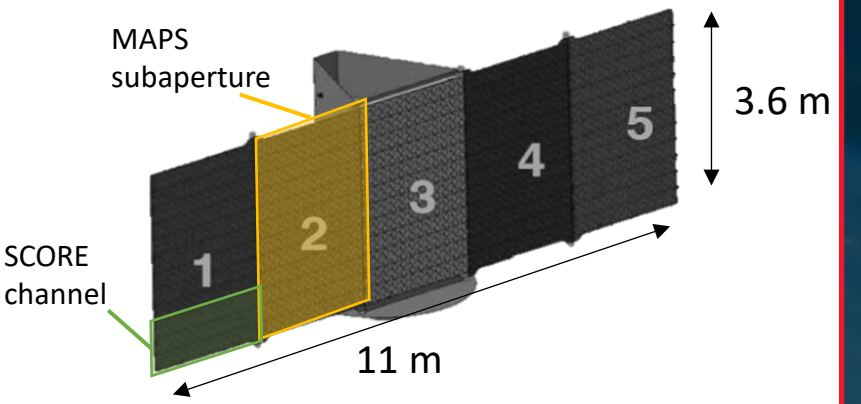
MR-SYS-090	**The mission shall support potential operations with one or more additional companion satellite(s)**
	The requirement is aimed at allowing bistatic observations based on one or more satellites flying in convoy, in formation or in other bistatic configurations with ROSE-L. This would enable the retrieval of enhanced information from multiple viewing angles, and, in case of single-pass interferometry configurations, the provision of enhanced forest height and forest biomass information, as well as Digital Elevation Models and forest vertical structure information, as discussed in Section 3.2.2.2. Effective companion operations rely on the synchronization between the companion receiver and the active ROSE-L instrument. Synchronization can be of three types: course time, fine time and phase synchronization. Coarse time synchronization is demanded to match the timing of the data-take and the steering patterns of the illuminator antenna. This requires precise control on timing and transparent operations of ROSE-L, to enable burst and sub-swath alignment. Fine time synchronization refers to the estimation of the return echo window. It only affects the data volume to be downloaded and it is deemed to fully rely on onboard companion data processing capabilities. The last, and crucial, type of synchronization is phase synchronization, aimed at compensating the phase differences between the local oscillators. This shall be supported by ROSE-L by ensuring the capability of providing the master oscillator phase as reference to the GNSS receiver.



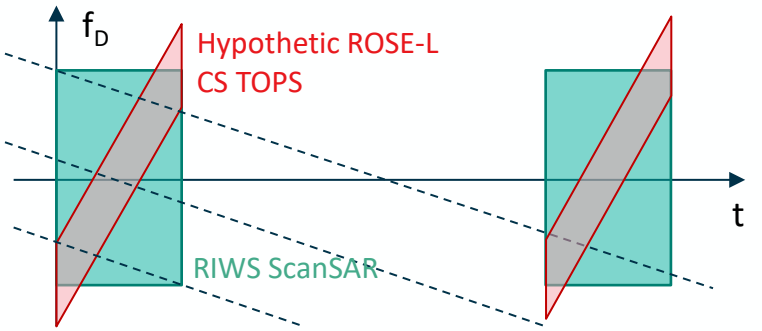
Companion Friendliness

Several aspects to be considered for supporting companion missions

- Transparency in operations
  - Data takes timing and associated SAR modes known/systematic
  - Relevant for both active and passive coflyers
- Illuminator antenna complexity
  - Digital beamforming
  - Relevant for both active and passive coflyers, but more critical for passive
- Transparency in transmitted pulses
  - PRF regular vs scrambled pulses, known vs unknown
  - Relevant only for passive coflyers
- Time synchronisation
  - Burst and echo window alignment, geo-tagged vs time-tagged vs Synch-link
  - Coarse time synch relevant for both active and passive, fine time synch only for passive
- Phase synchronisation
  - GNSS receiver sharing SAR oscillator, Synch-link
  - Relevant only for passive coflyers



- No need of implementing SCORE or 5-channel MAPS for mode compatibility. However, performance decrease to be expected
  - Possible TOPS, replacing MAPS, to get back DTAR (at cost of resolution)
  - 2-, 3-channel MAPS solutions to be investigated



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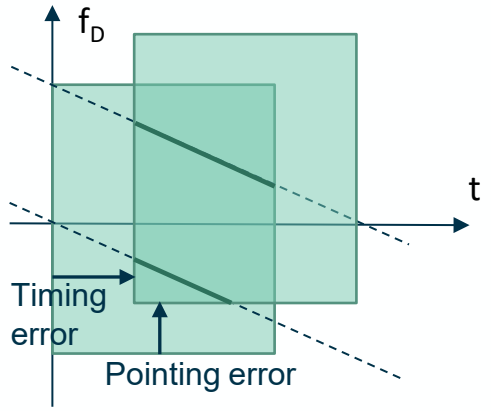
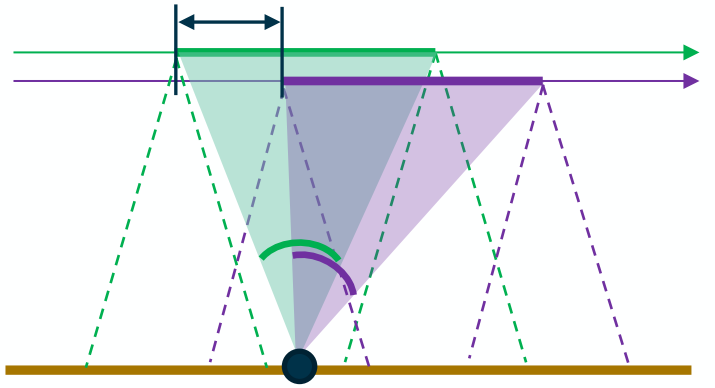


Timing mis-synchronization example for active companion. Similar principle (half stringent req.) is also applicable to bistatic Doppler frequencies



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- In ROSE-L, the USO is not disciplined by the GNSS. Solution based on 1-PPS GNSS signal is not applicable.
- Solution based on GNSS using SAR USO as reference followed by data-driven approach is viable (same as EE10 Harmony)
- ROSE-L Requirements
  - The GNSS driven by the SAR instrument ultra-stable reference oscillator (USO). To be noted that this is a functional requirement, without minimum accuracy imposed.
  - The SAR instrument USO centre frequency shall be monitored and provided with an accuracy of better than 10 mHz (3-sigma) at carrier centre frequency (L-band).
- Synchronization strategy and achievable accuracy to be investigated

New ESA Studies on ROSE-L Companion Satellites (CS)

BACKGROUND AND JUSTIFICATION

- Bi/Multi-static SAR based on ROSE-L to be potentially achieved through variety of constellation options or geometries, each optimised for different science, application, and service domains.
- Advance understanding in a significant number of environmental processes and progress the implementation of the Earth Observation Science Science Strategy 2040
- Capitalise on ESA and Member State investments in mission development including ROSE-L, EE10 Harmony and SAOCOM-CS

IMPLEMENTATION

- Two parallel science studies to identify user-level information products, the corresponding observation needs and map them into candidate CS architectures, in both XT and AT configurations.
  - Addressing two temporal scenarios: 1) short-term implementation option; 2) longer term development scenario
  - To be KO in Q3 2025
- To be followed by Pre-Phase 0 study conducted by industry and guided by harmonised inputs from science studies

Conclusions and Future Outlook

ESA with industry and together with EC preparing "expansion" and "next generation" of Copernicus SAR missions

- ROSE-L and S1NG bring high performance imaging, wide swath and frequent revisit capability
- Sentinel-1 and ROSE-L shall be addressed as an operational dual-frequency system, not in isolation
- ROSE-L Critical Design Review concluded with mission in good health and no foreseen show-stoppers to enter Phase D

In parallel, ESA actively working to advance the development of candidate ROSE-L companion missions, with dedicated studies underway to explore their feasibility

- Can ROSE-L be considered a companion friendly mission?

No agreed definition of 'companion friendliness' → Question for Multistatic SAR community:

<u>How about defining a Companion Friendliness Level (CFL) index?</u>

E.g. CFL0 – no transparency on operations and pulse timing

CFL1 – transparency , GNSS and SAR NOT sharing oscillator

CFL2 – transparency , GNSS and SAR DO share oscillator

CFL3 – transparency , Synch-link