

living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE
OF OUR PLANET FROM SPACE



The Copernicus polaR Ice and Snow Topography Altimeter (CRISTAL): supporting Copernicus Services and polar science

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26 May 2022

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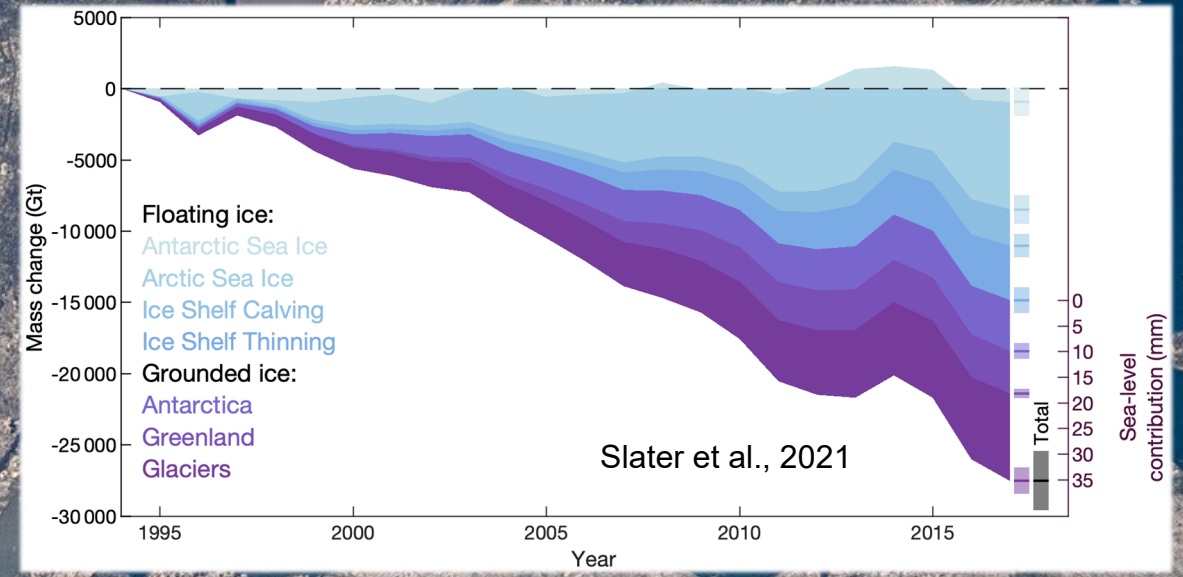
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The melting cryosphere



Over 1994-2017 we have lost **28 trillion tonnes** of ice
 That is a 10-km cube of ice every year!

Graphics by Planetary Visions

Two main effects

Photograph: Benoit Lecavalier/PA

Loss of land ice
→ rises sea level
→ coastal impacts

Loss of sea ice
→ Decreases albedo
→ Positive climate feedback

First outlined in 2008 and updated regularly

It calls for mitigation and adaptation actions in three priority areas:

1. Climate Change and Safeguarding the Arctic Environment

- livelihoods of indigenous peoples, Arctic environment.

2. Sustainable Development in and around the Arctic

- exploitation of natural resources e.g. fish, minerals, oil and gas), “Blue economy”, safe and reliable navigation (e.g. the Arctic Northern Sea Route).

3. International Cooperation on Arctic Issues

- scientific research, EU and bilateral cooperation projects, fisheries management/ ecosystems protection, commercial fishing



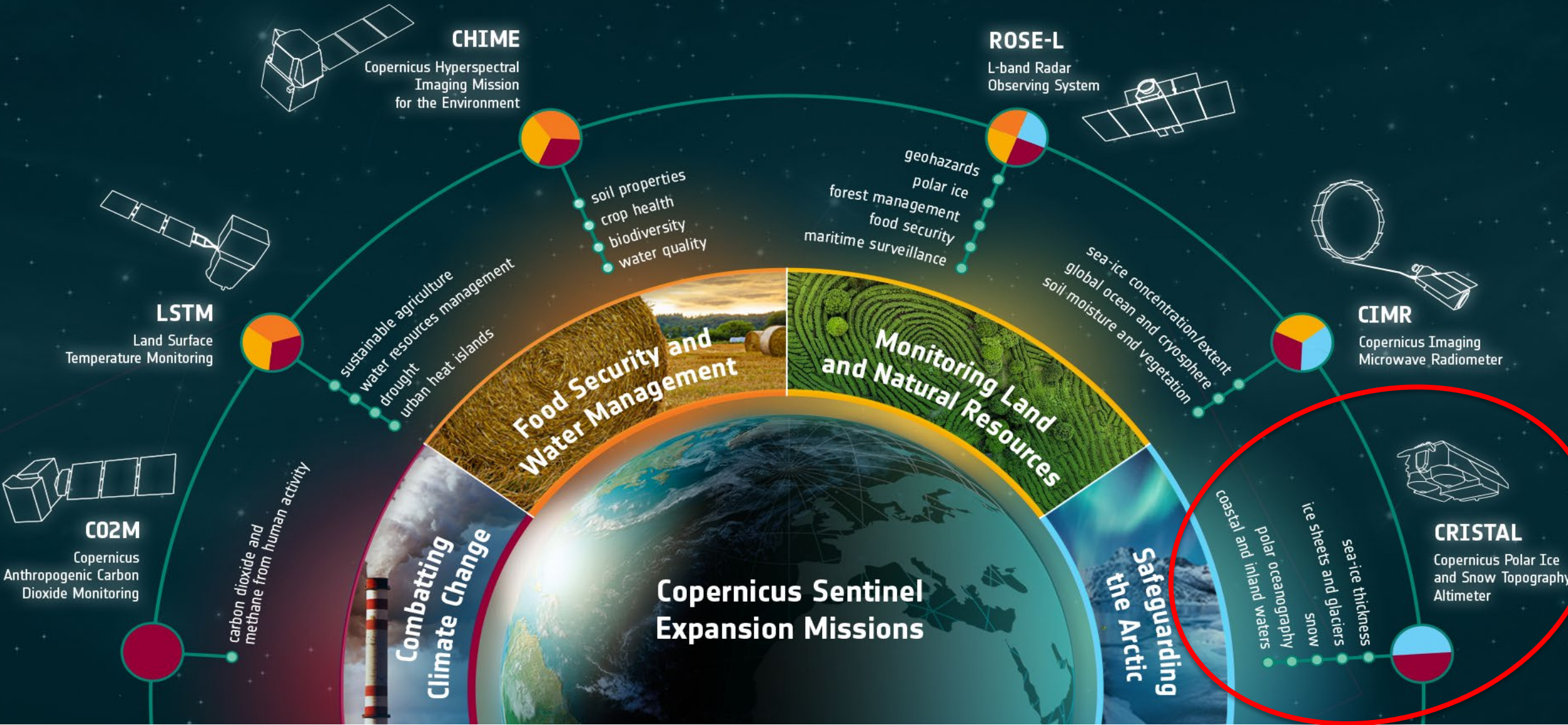
CRISTAL is being developed as a key contribution to Europe’s planned response to the need for monitoring of the polar regions



PROGRAMME OF THE EUROPEAN UNION

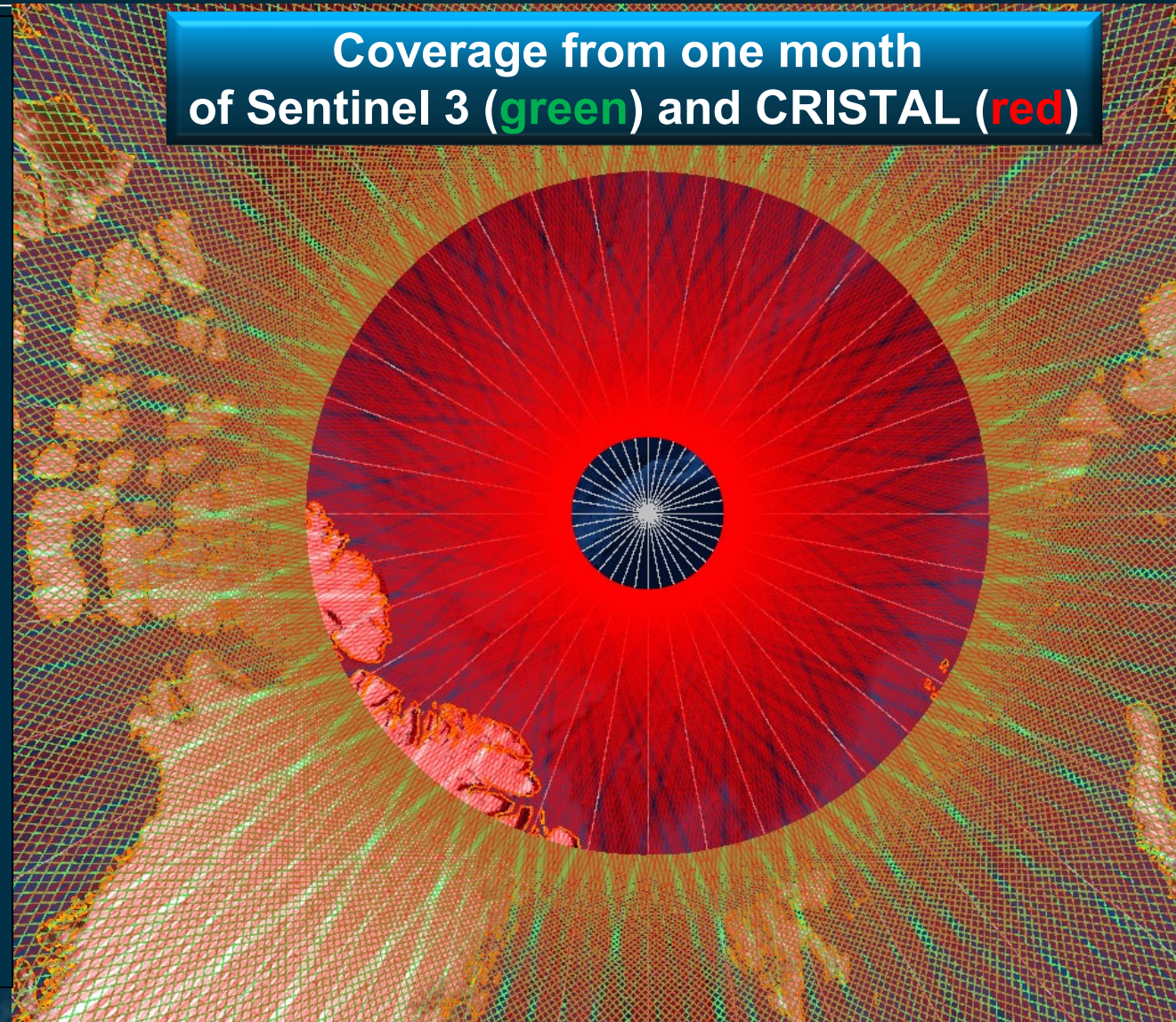
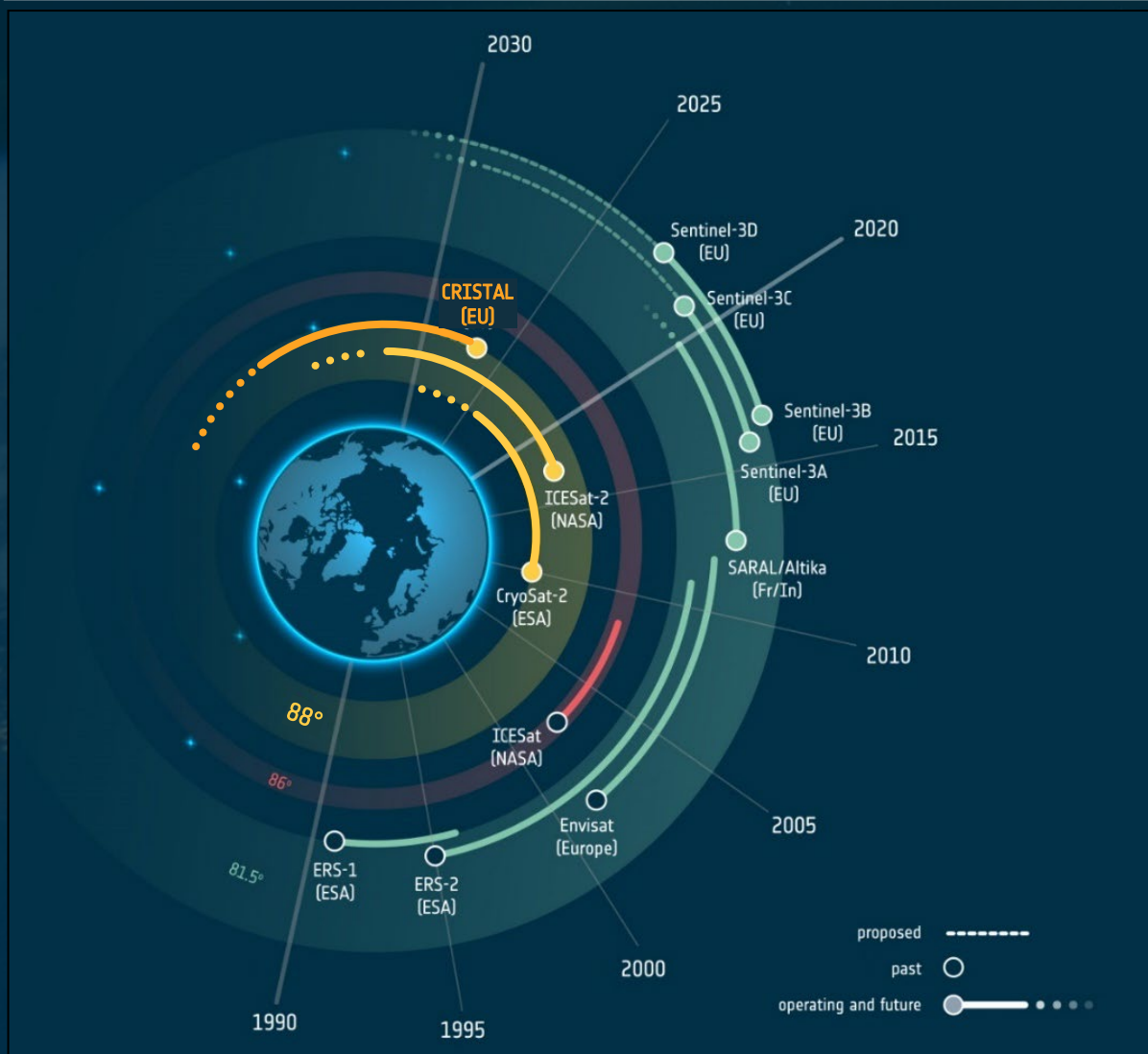


co-funded with



→ THE EUROPEAN SPACE AGENCY

Filling the 'hole at the Pole'



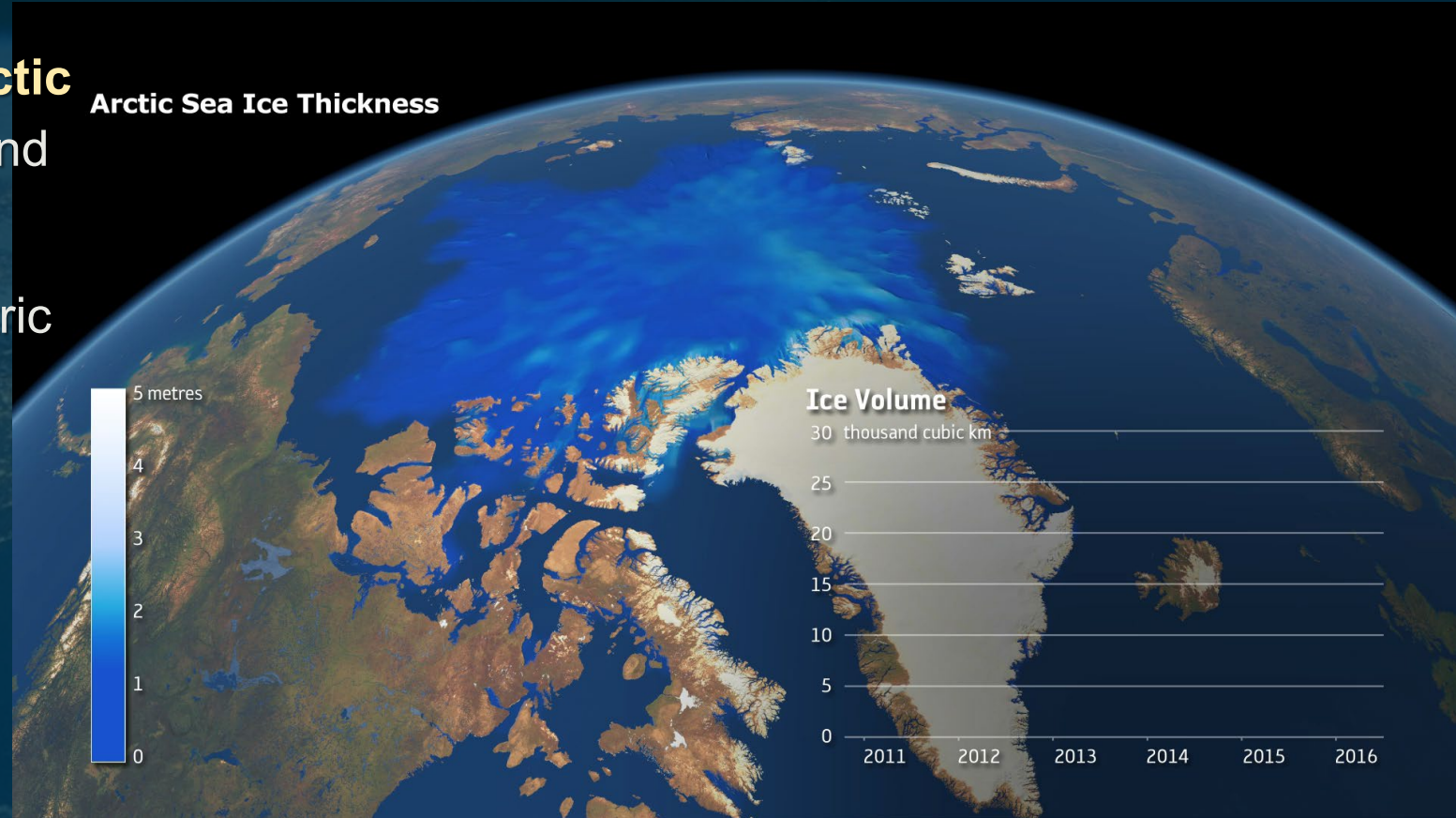
CRISTAL – a Copernicus Expansion Mission



CRISTAL directly addresses the **EU Arctic Policy** in strong synergy with CIMR and ROSE-L

Responds to needs for continual altimetric monitoring of Arctic Region North of 81.5°N

Builds on the heritage of CryoSat-2



The first high-resolution operational Radar Altimeter mission for the cryosphere

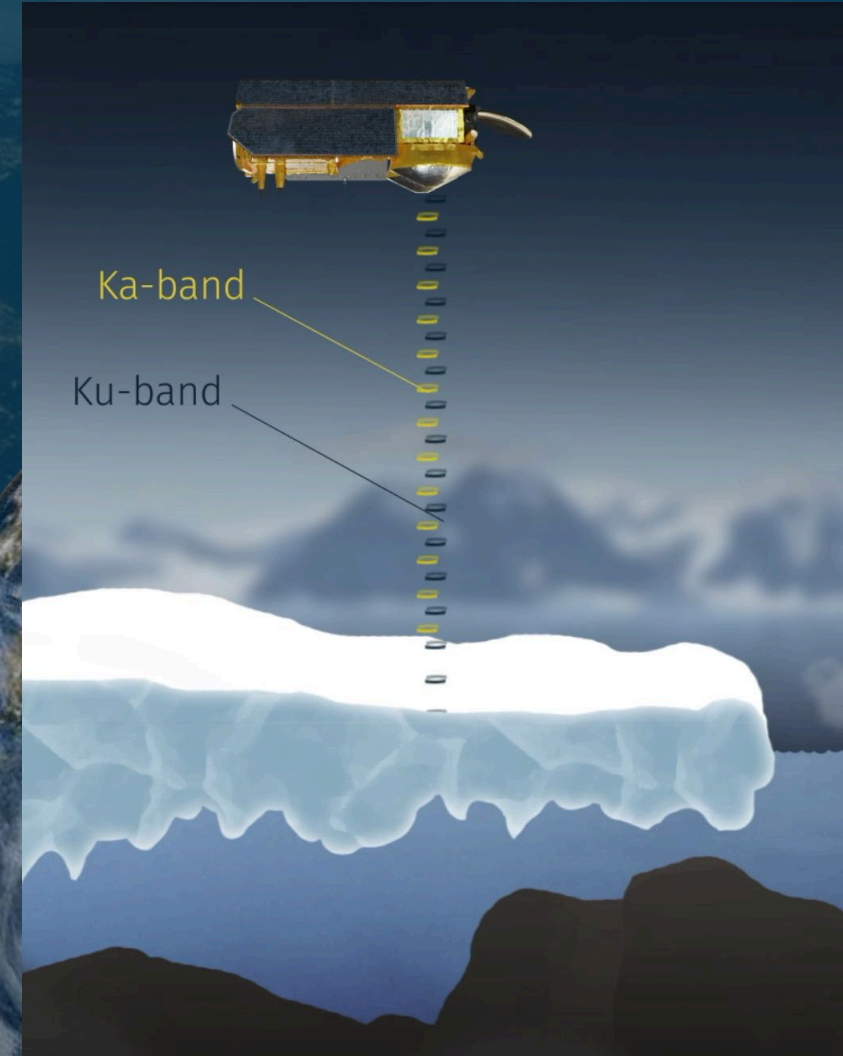


CRISTAL will measure snow depth using Ku- & Ka-band

- Snow depth is important in itself - for local and global energy and freshwater budget
- **Essential** for retrieving sea ice thickness from altimetry



$$\text{Sea ice thickness} = \frac{f_i \rho_w}{\rho_w - \rho_i} + \frac{h_s \rho_s}{\rho_w - \rho_i}$$



Credits: Isobel Lawrence et al., LPS22

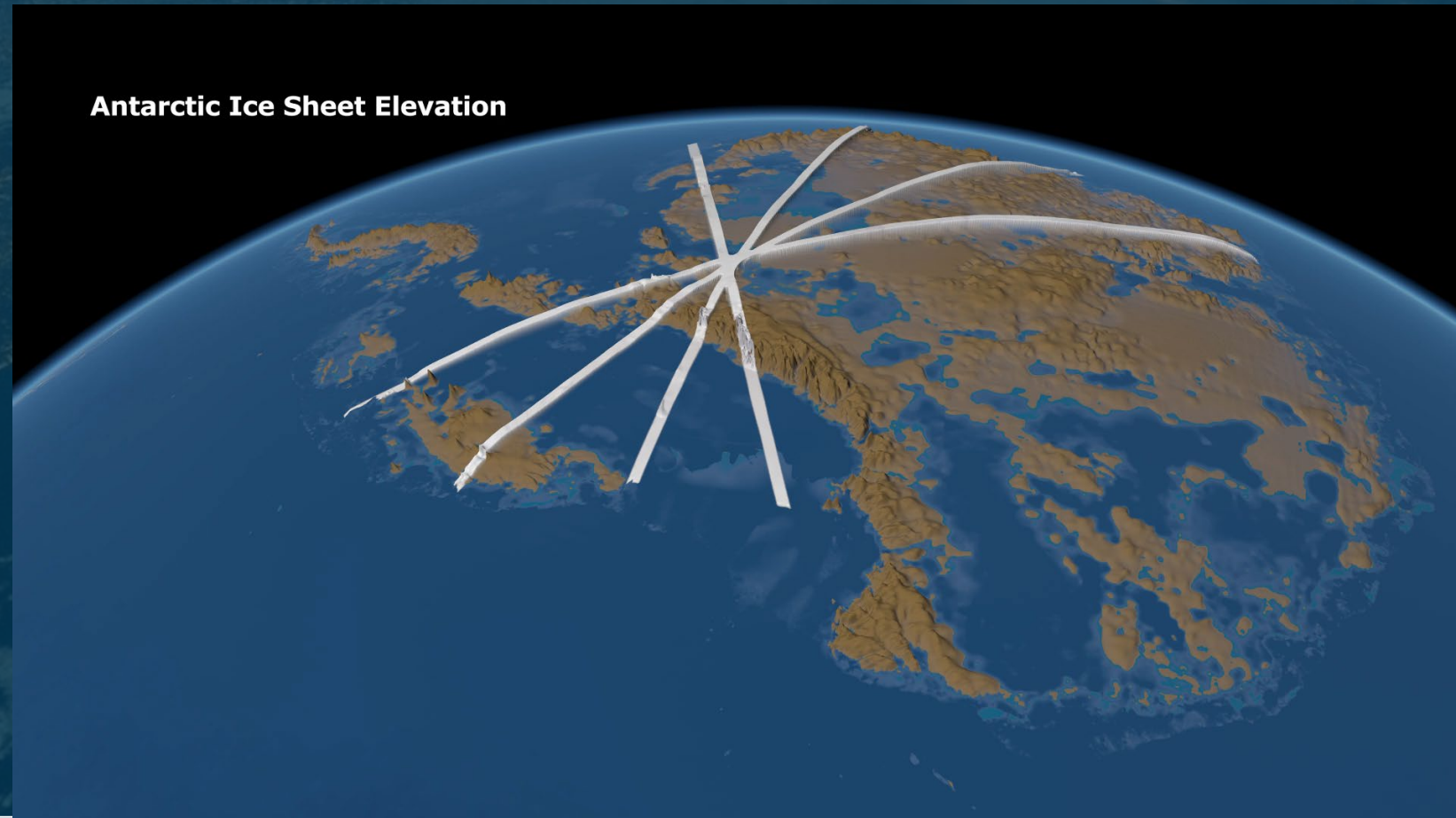


CRISTAL will provide:

high resolution **sea ice thickness** and **snow depth** measurements in polar regions
high resolution **land ice elevation** measurements of **glaciers, ice caps and ice sheets**

secondary objectives:

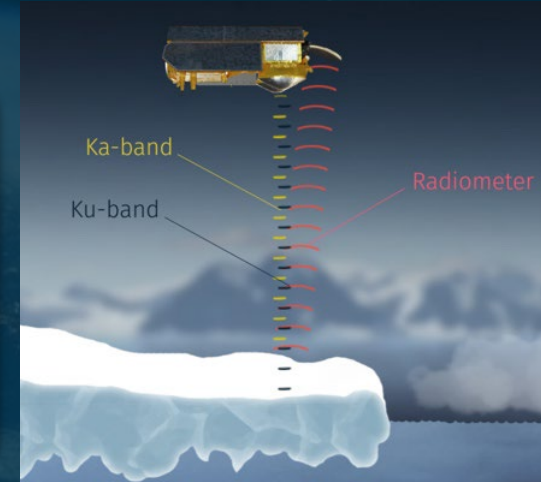
- ocean surface topography
- sea state
- coastal/inland water levels
- support to snow cover and permafrost applications



Based on CryoSat-2 heritage but with significant improvements

Instrument suite improvements:

- Ku-band Interferometric Synthetic Aperture Radar Altimeter with **Ka-Band channel for snow depth** retrieval
- Addition of **Passive Microwave Radiometer** for
 - wet troposphere correction (secondary mission objective)
 - potential contribution to ice and snow classification (primary mission objective)



Performance & operation improvements:

- **36% improvement of Sea ice freeboard measurement** resolution, by increasing bandwidth to 500MHz (CryoSat 320MHz)
- **Improved interferometric measurements** with **50%** improvement on elevation error
- **Higher precision monitoring of icebergs, ice lead discrimination** etc. with very high along-track resolution (up to **0.5m** with fully-focused SAR processing)
- **Tracking of glaciers** with added Open Loop operational mode



CRISTAL measurement modes

Surface	CryoSat-2				CRISTAL			
	Mode	Tx. pattern	Rx window	Tracking	Mode	Tx. pattern	Rx window	Tracking
Sea Ice and Icebergs	SAR	Closed Burst	60 m	CL	<u>SARIn</u>	<u>Open Burst</u>	64 m	<u>OL</u> and CL
Ice sheets, interior	LRM	Closed Burst	60 m	CL	<u>SARIn</u>	Closed Burst	256 m	OL and CL
Ice sheet margins, glaciers	SARIn	Closed Burst	240 m	CL	SARIn	Closed Burst	256 m	OL and CL
Open Ocean	LRM	Closed Burst	60 m	CL	<u>SAR</u> <u>RMC</u>	Closed Burst	<u>32 m</u>	<u>OL</u>
Coastal Region	SAR	Closed Burst	60 m	CL	<u>SAR</u> <u>RMC</u>	Closed Burst	<u>32 m</u>	<u>OL</u>
Inland waters	SAR / SARIn	Closed Burst	60 / 240 m	CL	<u>SAR</u>	Closed Burst	<u>32 m</u>	<u>OL</u>

Credits: A. Garcia-Mondejar, V. Lieb, E. Mank et al.,. Poster at LPS22

CRISTAL Mission – the key requirements

Applications / Geophysical Products	Measurement uncertainty	Latency requirements
Sea ice freeboard	< 3 cm over segments \leq 25 km	6 hours
Sea ice thickness	< 10 cm	24 hours
Snow depth on sea ice	< 5 cm	24 hours
Land ice/glacier elevation	< 2 m	NTC (< 30 d)
Iceberg detection		24 hours
Ocean L2 products	< 3.5 cm (for 1-Hz SSH NTC)	NRT (< 3 h) STC (< 48 h) NTC (< 30 d)
Ocean L1 products		STC (< 48 h) NTC (< 30 d)

Most products **already validated** (CryoSat-2) but will be **enhanced** with **higher accuracies**
 New products for **Snow depth** and **Iceberg detection**

CRISTAL and Copernicus Services



Copernicus Polar Expert Group (PEG) Reports (2017)

ESA CRISTAL Mission Requirements Document

<p>C3S</p>	<ul style="list-style-type: none"> • Ice sheet topography • Sea ice thickness & volume • Snow depth • Global sea level 	
<p>CMEMS</p>	<ul style="list-style-type: none"> • Sea ice thickness • Sea level anomaly & currents • Waves 	
<p>CLMS</p>	<ul style="list-style-type: none"> • Ice sheet and glaciers topography • Snow depth 	
<p>CAMS</p>	<ul style="list-style-type: none"> • Snow depth 	
<p>EMS</p>	<ul style="list-style-type: none"> • Snow depth • Global sea level • Lake and river level 	



Dual-band allows exploration of snow/firn/ice interfaces

Otosaka, Shepherd, Casal et al.

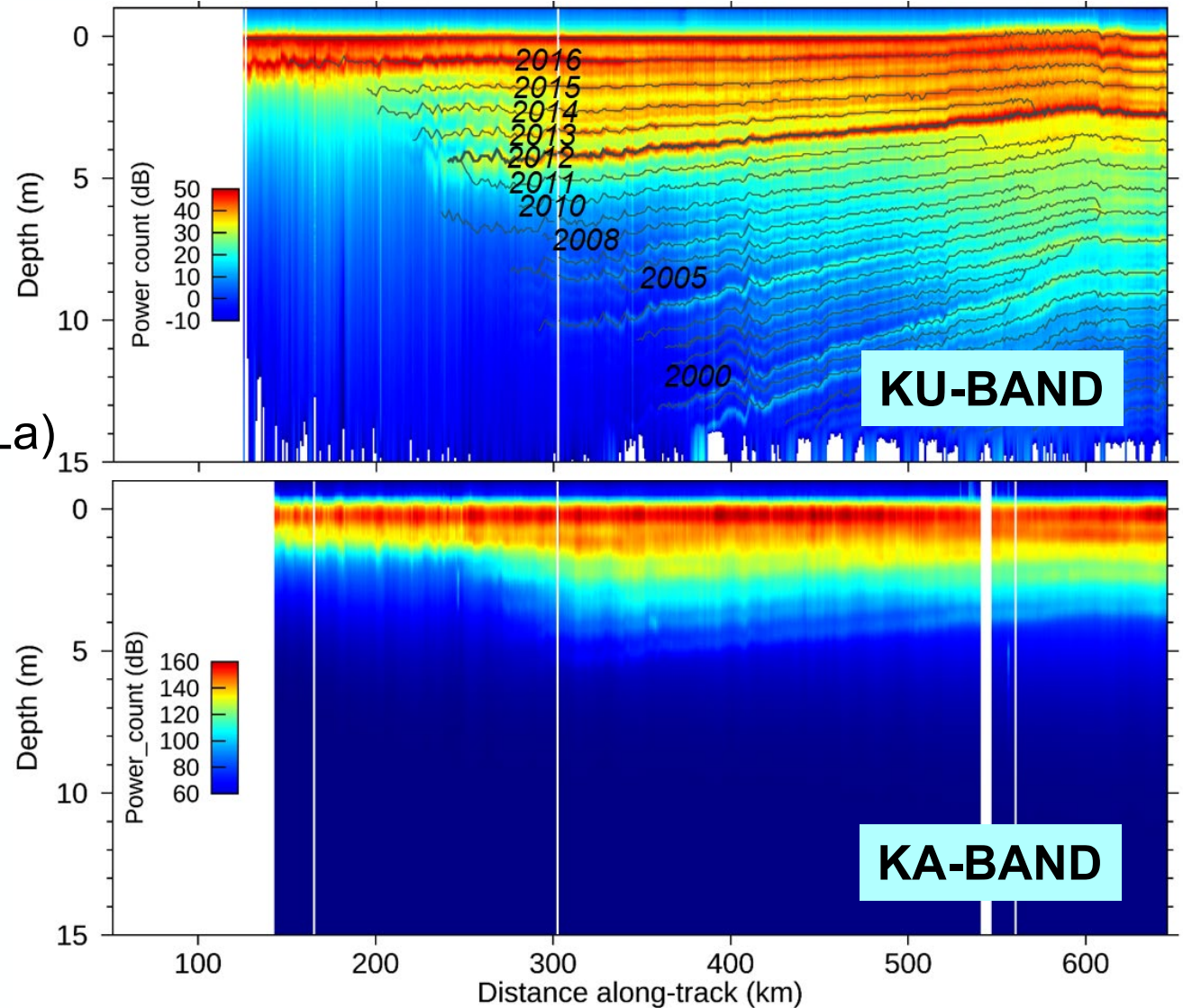


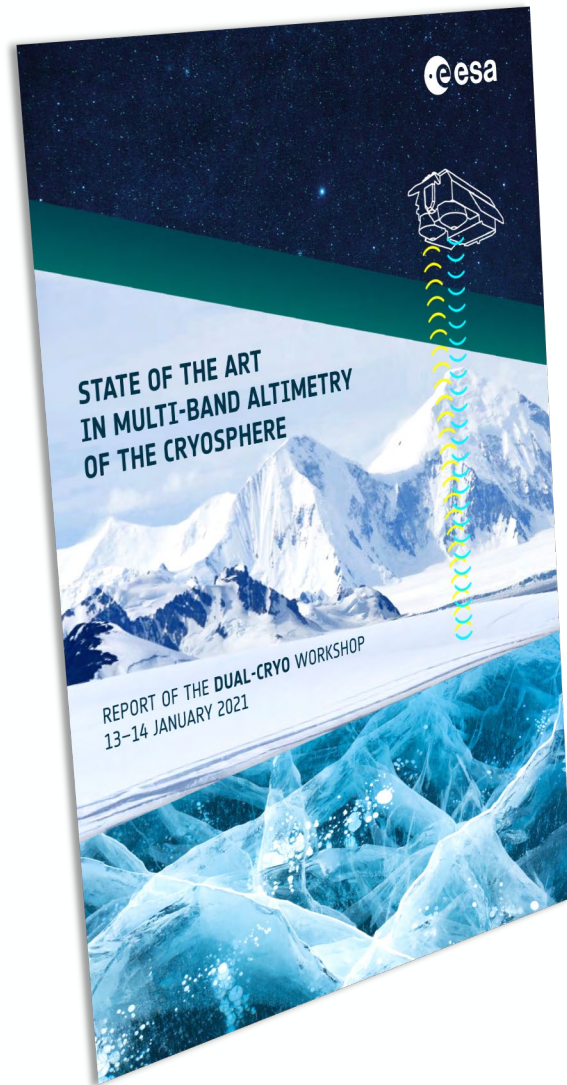
CryoVEx campaigns
ASIRAS (Ku), KAREN(Ka), ALS(La)
+ Firn Cores
+ Firn Models

Ka band mostly picks the surface, Ku penetrates and shows the layers

Fluctuations in radar penetration are correlated with fluctuations in densities

CRISTALAir, a new Ku/Ka airborne demonstrator is being designed and commissioned





P. Cipollini, G. March, A. Shepherd (eds.), “State of the art in multi-band altimetry of the cryosphere” , Report of the DUAL-CRYO Workshop, 13/14 January 2021. ESA reference ESA-EOPSM-CPTM-RP-4038, 32 pp.

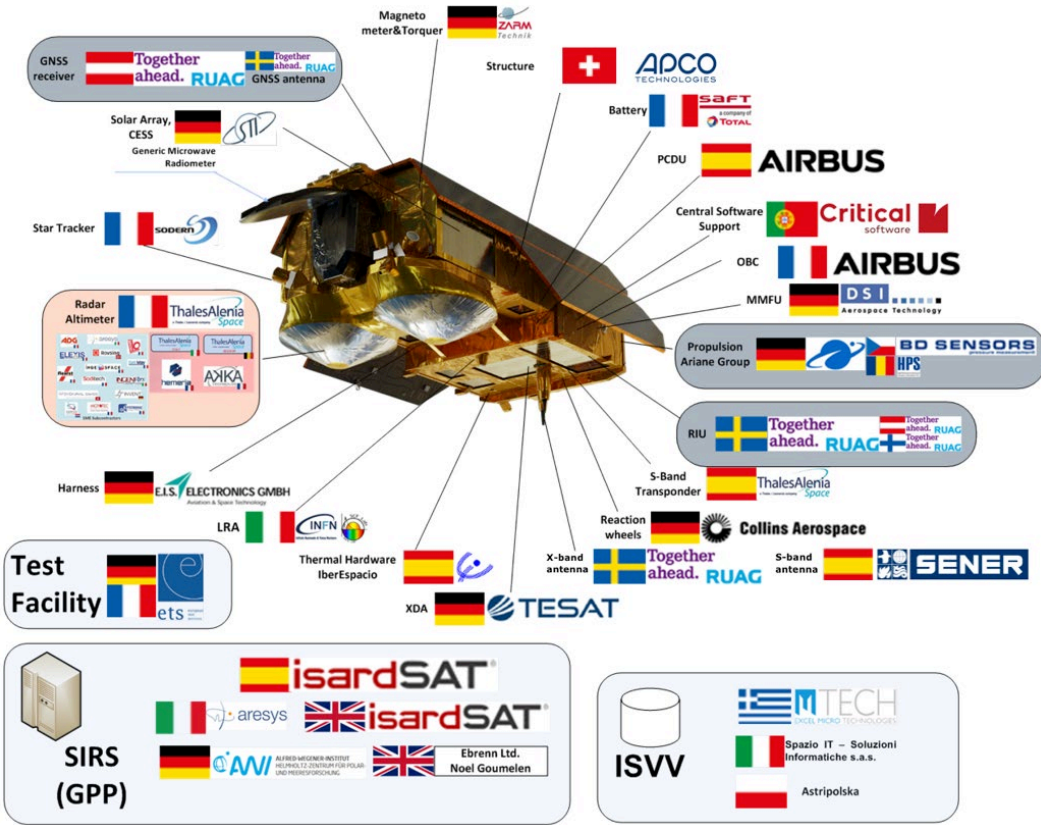
(Google ‘DUAL-CRYO’)

CRISTAL Space Segment Industrial organisation

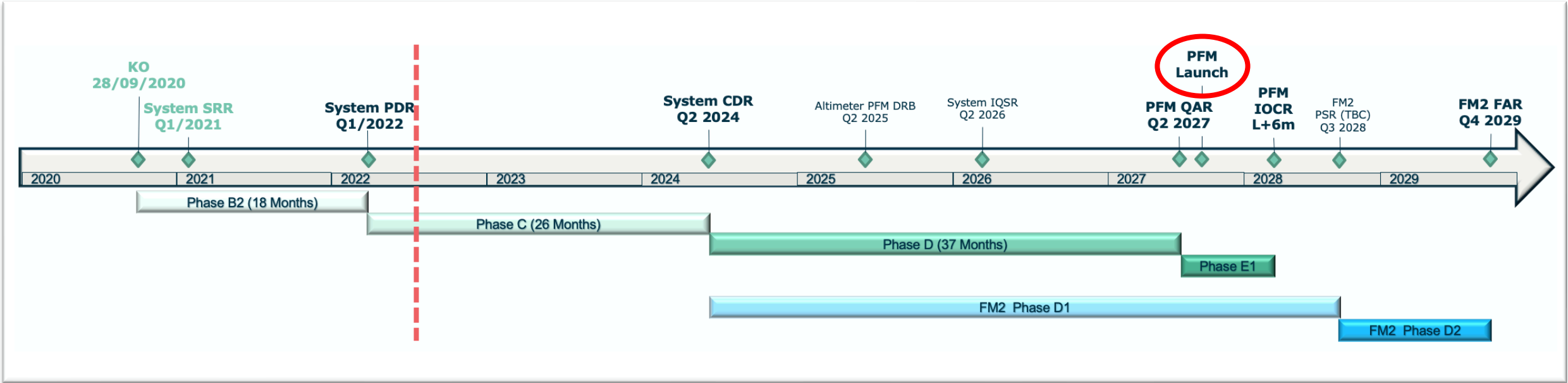


□ Consortium for Space Segment Development Phases B2/CD (for PFM + FM2) with large heritage in altimetry missions and collaboration experience (CryoSat-2, Sentinel-6),

- **Airbus (DE)** Mission & Satellite Prime contractor
- **Thales Aleniaspace (FR)** Altimeter Instrument prime contractor
- **IsardSAT (ES)** System and Instruments Retrieval Simulator (SIRS) and Ground Processor Prototype (GPP) prime
- 17 countries
- 50+ companies, 8% SME's



CRISTAL Main project phases and milestones



	KO	SRR	PDR	CDR	PFM QAR	FM2 FAR
Satellite	28/09/20	Feb-Mar'21	Feb-Mar'22	May'24	Jun'27	Oct'29
Altimeter	28/09/20	Feb-Mar'21	Feb-Mar'22	Apr'24	May'25	Jan'26



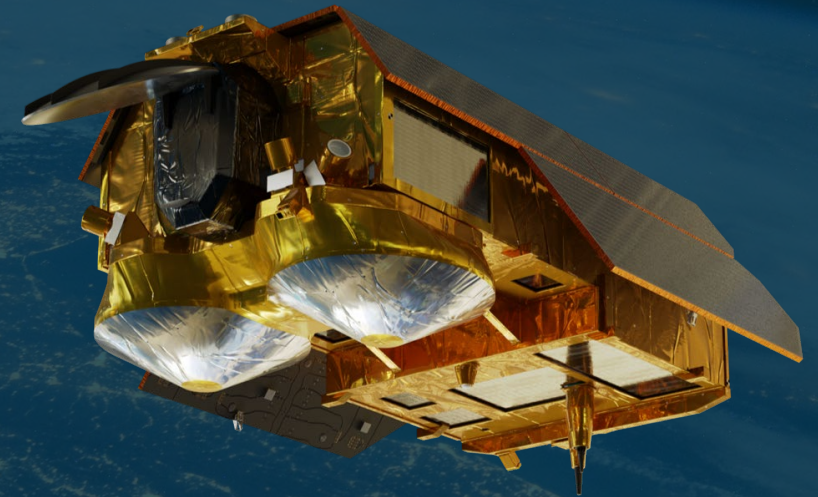
Objectives: Monitor **sea ice, icebergs, land ice, glaciers**, but also ocean, coasts and inland waters

High inclination mission, continues the legacy of CryoSat-2, with improved performance

Dual-frequency Ku/Ka SAR altimeter, Ku is interferometric

Improved bandwidth: 500 MHz in both Ku and Ka

- Open burst over sea ice and icebergs → improved resolution
- Flexible open loop/closed loop tracking
- AMR-CR radiometer with HRMR for oceanography, coastal altimetry, ice classification



Status: system PDR successfully completed – Started Phase C
On track for CRISTAL-A launch in 2027
(CRISTAL-B at some point in next decade)

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