



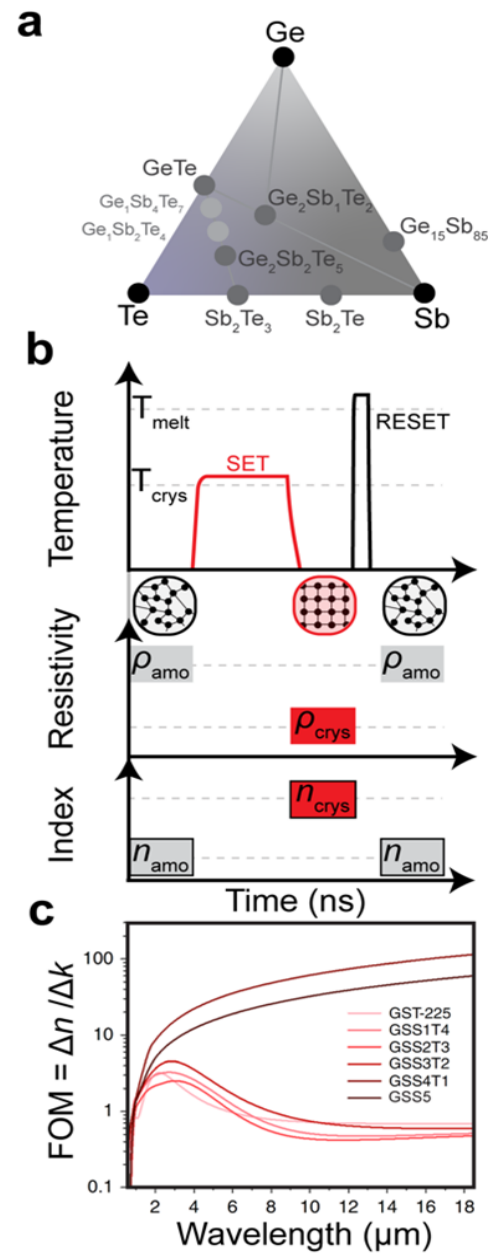
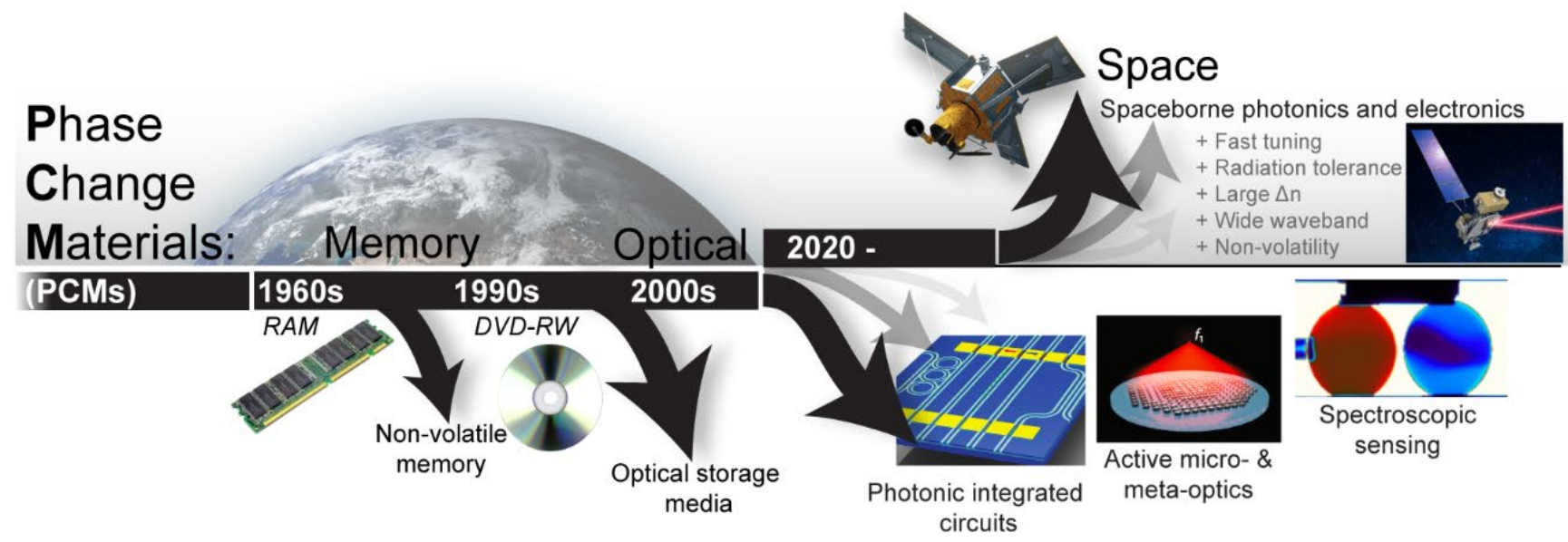
Space-qualified Chalcogenide Materials through ISS MISSE Exposure — from property to application

Hyun Jung Kim¹ and Juejun Hu²

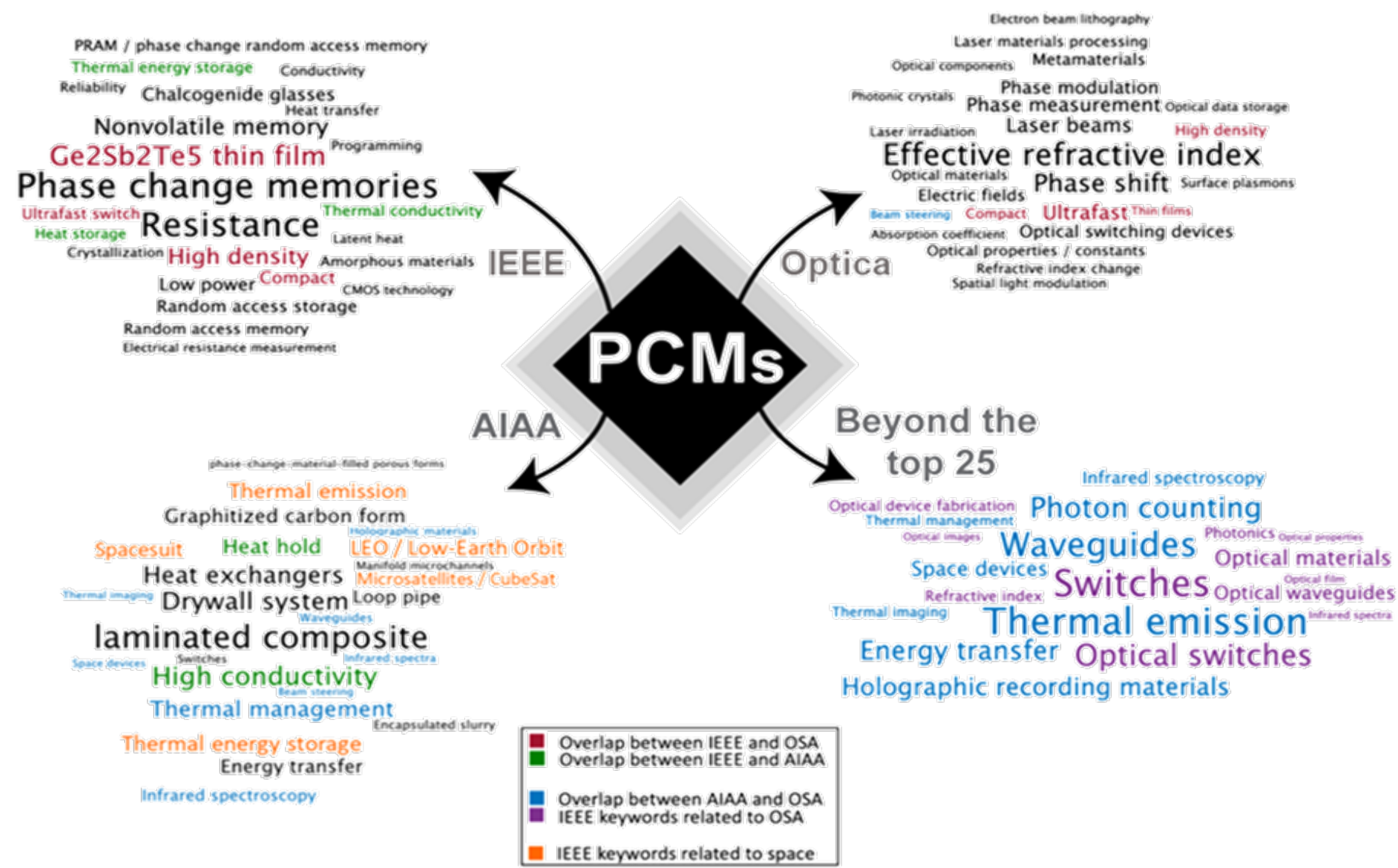
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November 29th, 2022

Prototypical phase-change materials and their characteristics, application-driven interest since 1960



Evidence of PCM research can, and should, expand from terrestrial to space applications from keywords searching



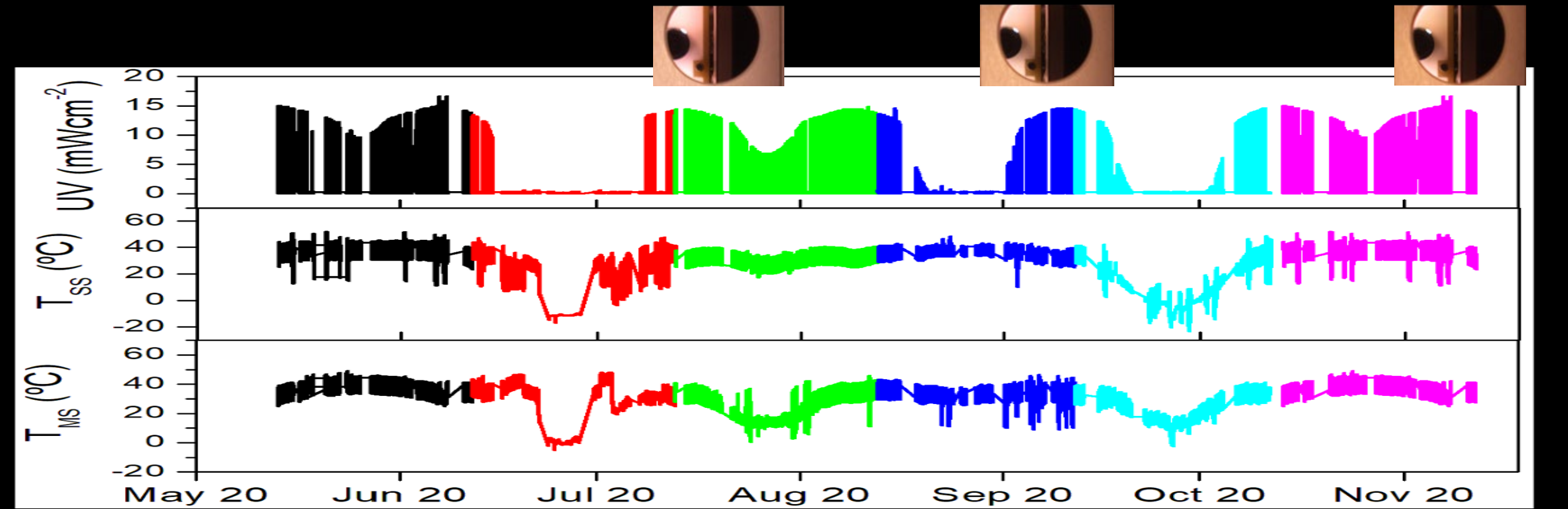
MISSE



- MISSE - Materials International Space Station Experiment
- Began at NASA Langley in 1999
- First external payload on ISS
- Contains individual test specimens – materials and devices – exposed to the space environment (LEO, space below an altitude of 2,000 km)
- All specimens returned to Earth for analysis
- Determine the space environment effects on the specimens (atomic oxygen, -120 °C to 120 °C temperature extremes, hard vacuum, UV radiation, charged-particle radiation (electrons, protons, light ions, heavy ions), orbital debris, micro gravity, micrometeoroids, and plasma-spacecraft interactions)
- Platform is now called MISSE-FF (Flight Facility) and is 4-sided (Ram, Wake, Zenith, Nadir)
- MISSE can provide testing of lunar surface environmental parameters as well
- PCMs ($\text{Ge}_2\text{Sb}_2\text{Te}_5$, $\text{Ge}_2\text{Sb}_2\text{Se}_4\text{Te}_1$, and Sb_2Se_3), along with PCM-based tunable filters, were delivered to the Zenith & Wake on ISS as part of MISSE-14 test campaign



On-Orbit Photographic Images & Environment Flight Data



Launch
02/20/2021

Unpack / unsealing
04/08/2021

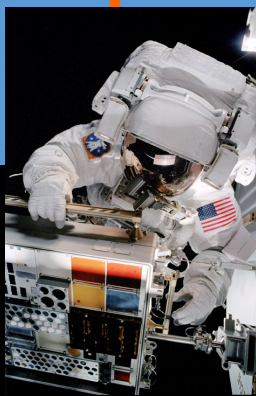
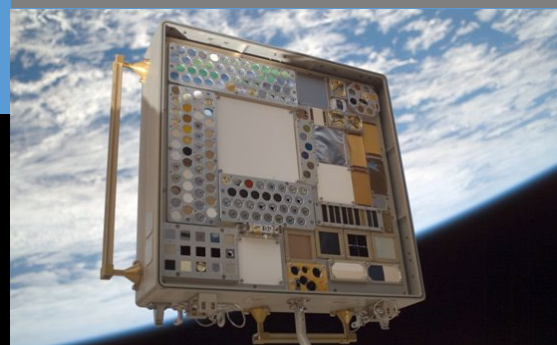
Deployment on orbit
04/25/2021

Exposure & monitoring
06/21/2021-12/6/2021
(148 days 21 hours 11 minutes)

Return
01/25/2022

- Preparation
- Preflight characterization

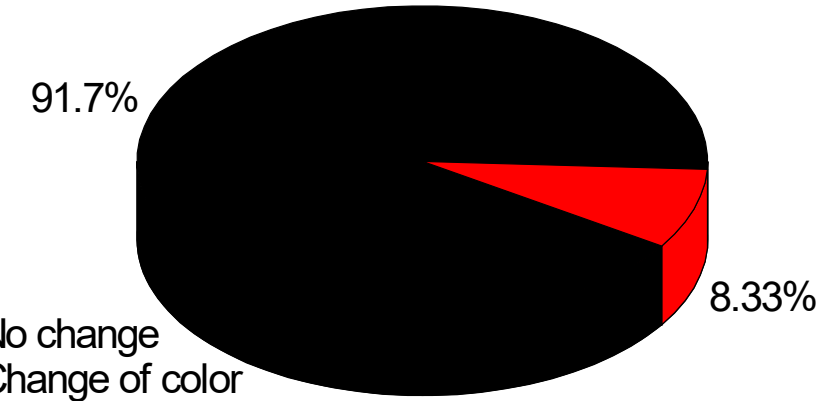
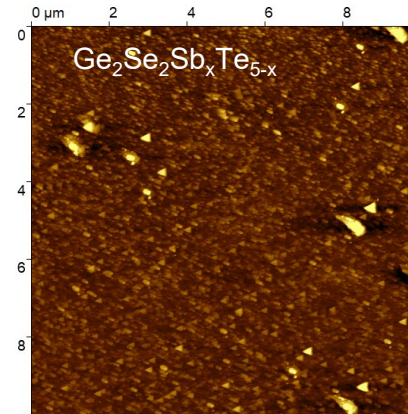
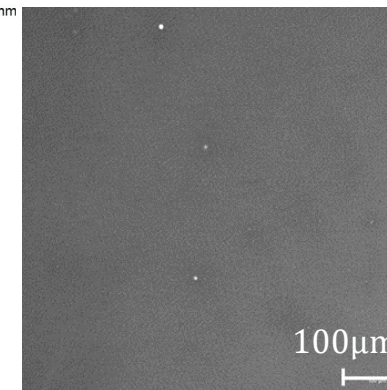
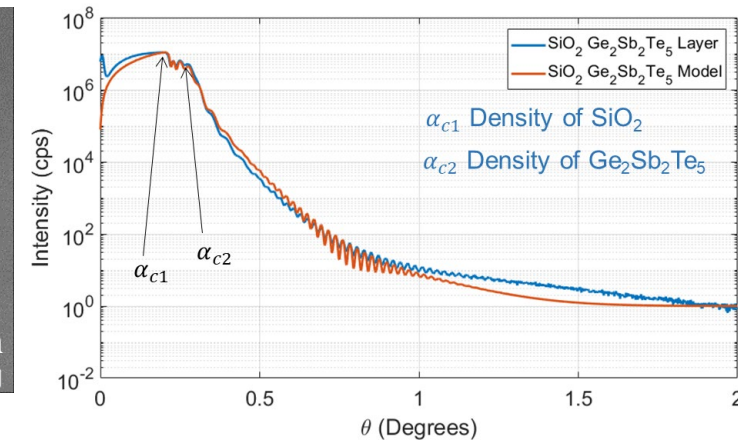
- Retrieval
- Post flight characterization



Results of Qualitative Analysis of Images and Quantitative Analysis



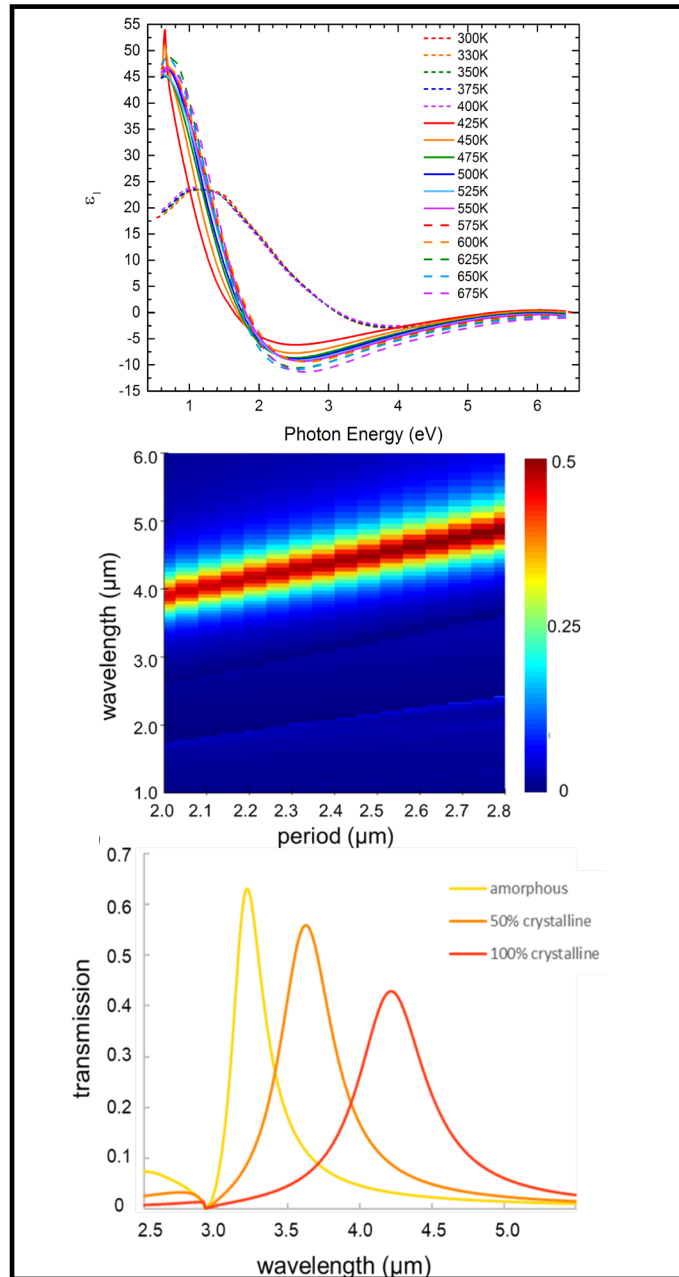
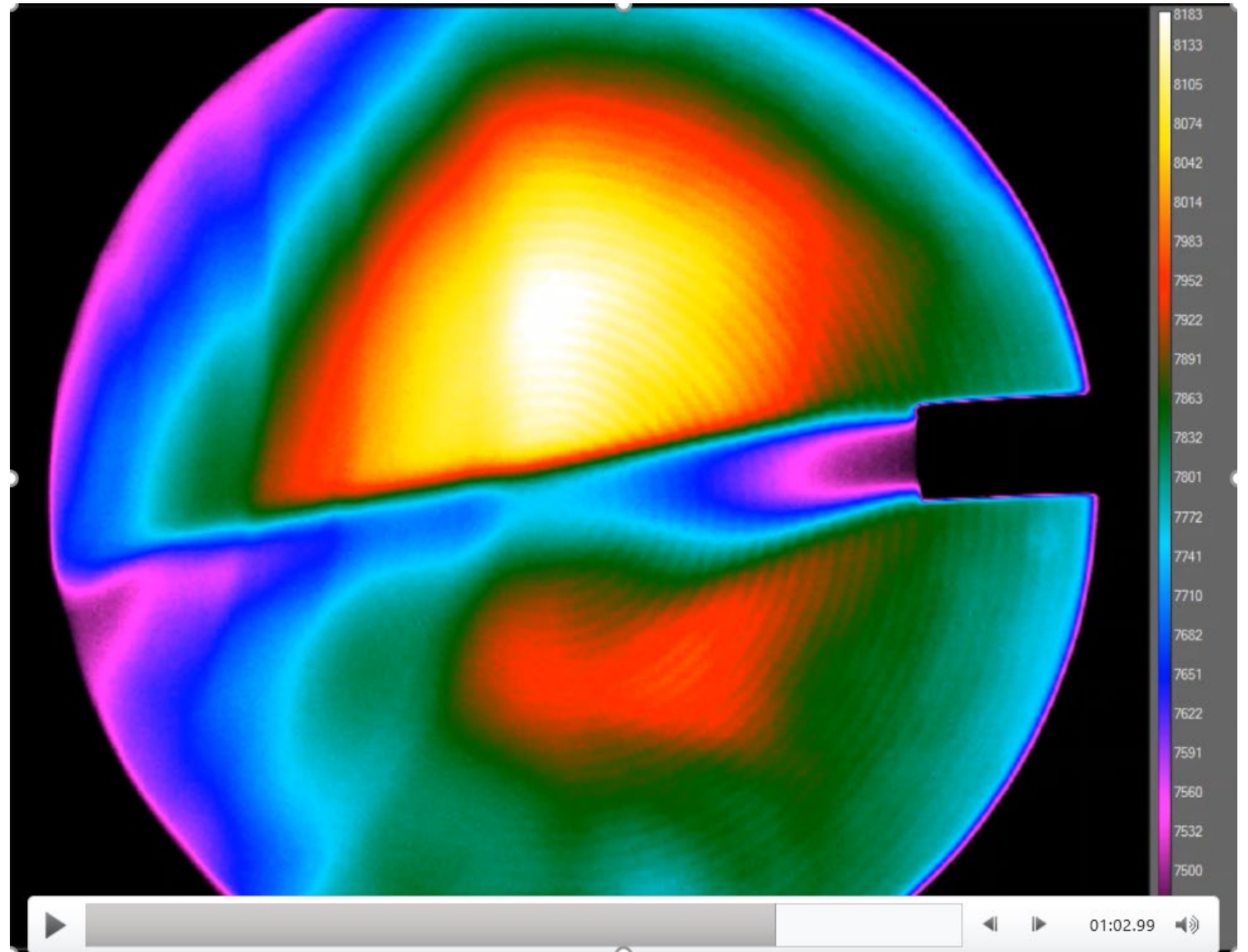
- Complete image data for the 24 exposed specimens
 - 91% of the specimens did not show a change
 - 9% demonstrated a change in color only, not texture (only non-SiO₂ capping layered specimens)
- On-going physical and optical properties characterization
- PCM-based photonics / electronics performances are highly dependent on the properties



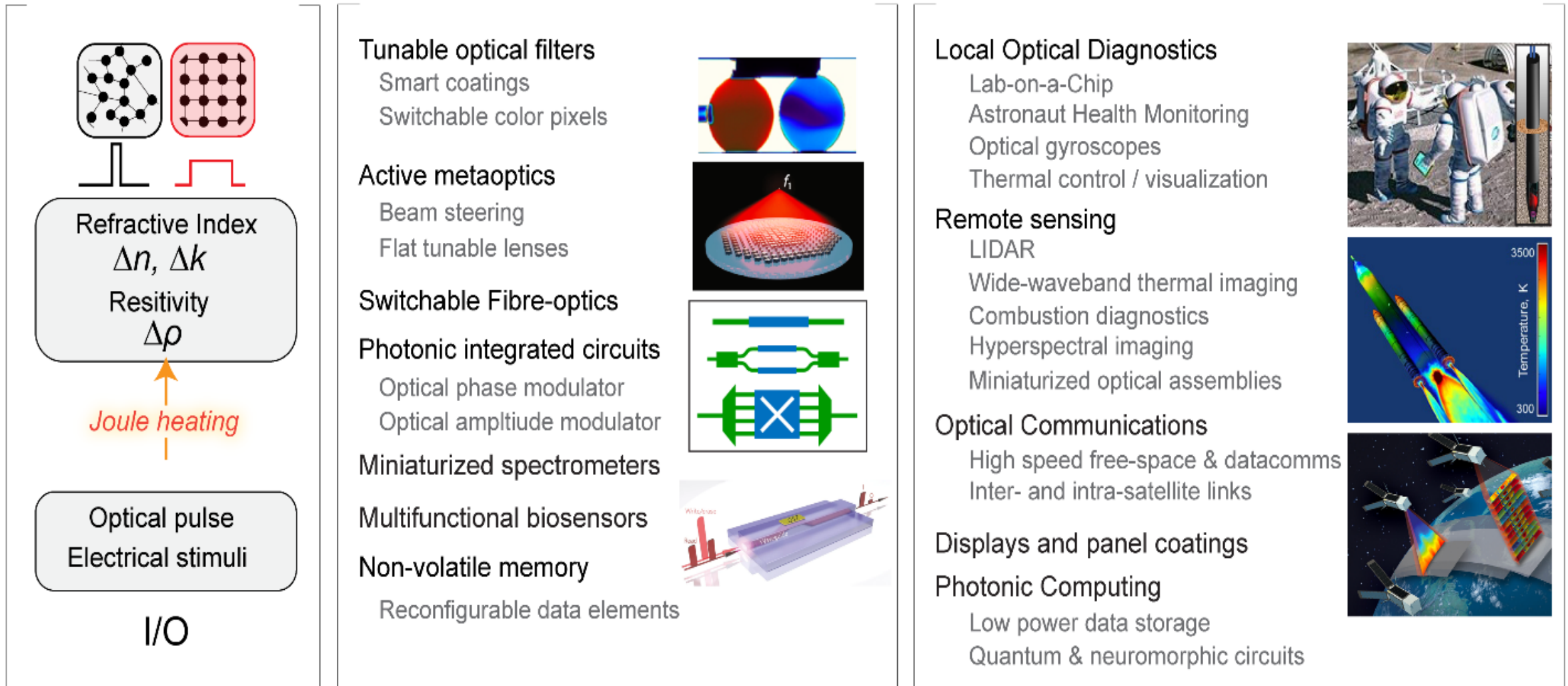
Sample	CaF ₂		PCM			SiO ₂		
	Density (g/cm ³)	Roughness (nm)	Density	Thickness	Roughness	Density	Thickness	Roughness
Substrate	3.47	2.9						
SiO ₂	3.1	1.1				2.2 (-3%)	80.0 (-2%)	4.3 (-5%)
Ge ₂ Sb ₂ Te ₅	3.2	1.0	4.9 (-7%)	179.4 (-6%)	2.3 (-10%)	2.2	78.5	4.0
Ge ₂ Se ₂ Sb _x Te _{5-x}	-	-	4.6-4.8 (-7%)	104.7-110.4 (-6%)	2.2 (-9%)	-	-	-
Sb ₂ Se ₃	-	-	3.9 (-7%)	140.5-152.5 (-5%)	2.5 (-9%)	-	-	-



PCM-based actively tunable filter performance evaluation after the space exposure



PCM-based photonics for spaceborne applications based on technologies and subsystems

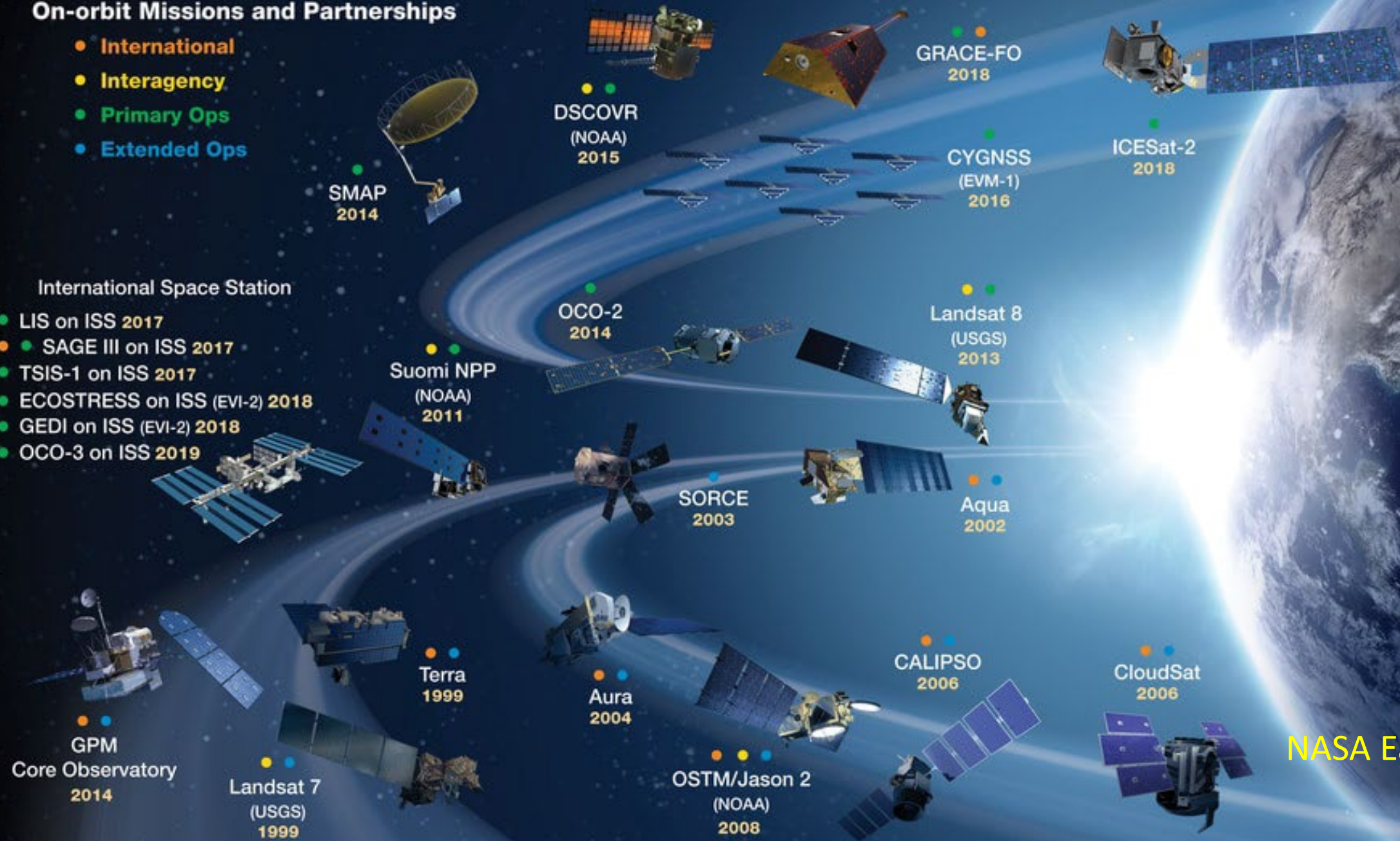


On-orbit Missions and Partnerships

- International
- Interagency
- Primary Ops
- Extended Ops

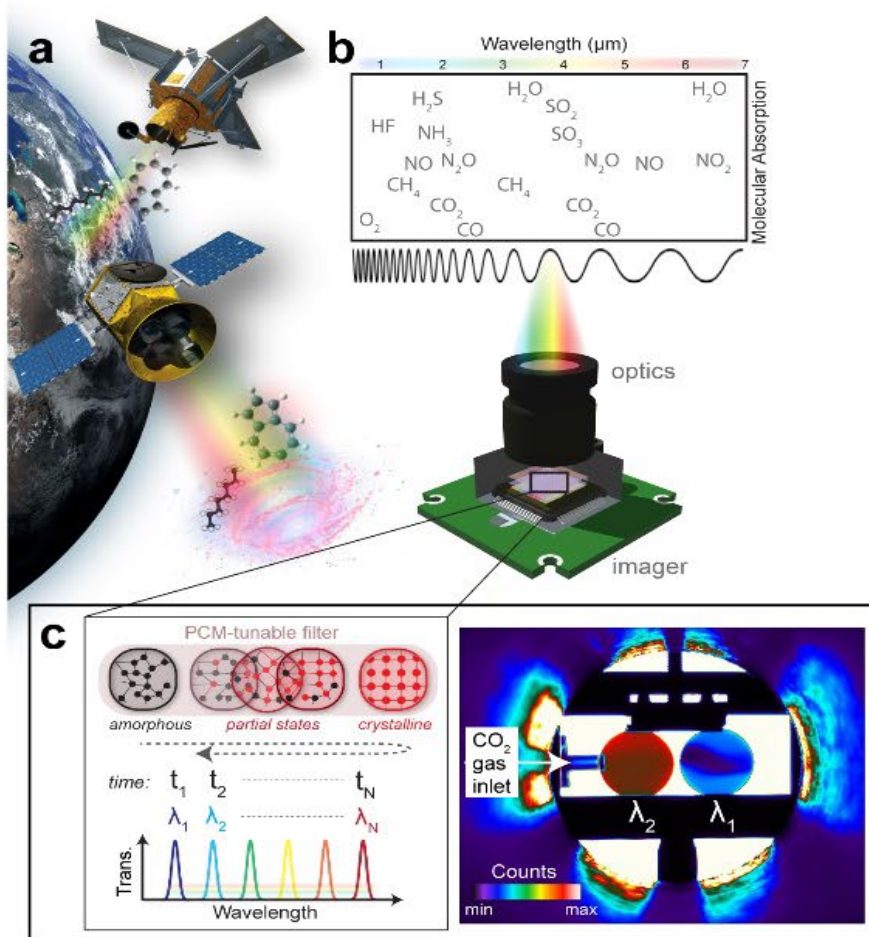
International Space Station

- LIS on ISS 2017
- SAGE III on ISS 2017
- TSIS-1 on ISS 2017
- ECOSTRESS on ISS (EVI-2) 2018
- GEDI on ISS (EVI-2) 2018
- OCO-3 on ISS 2019

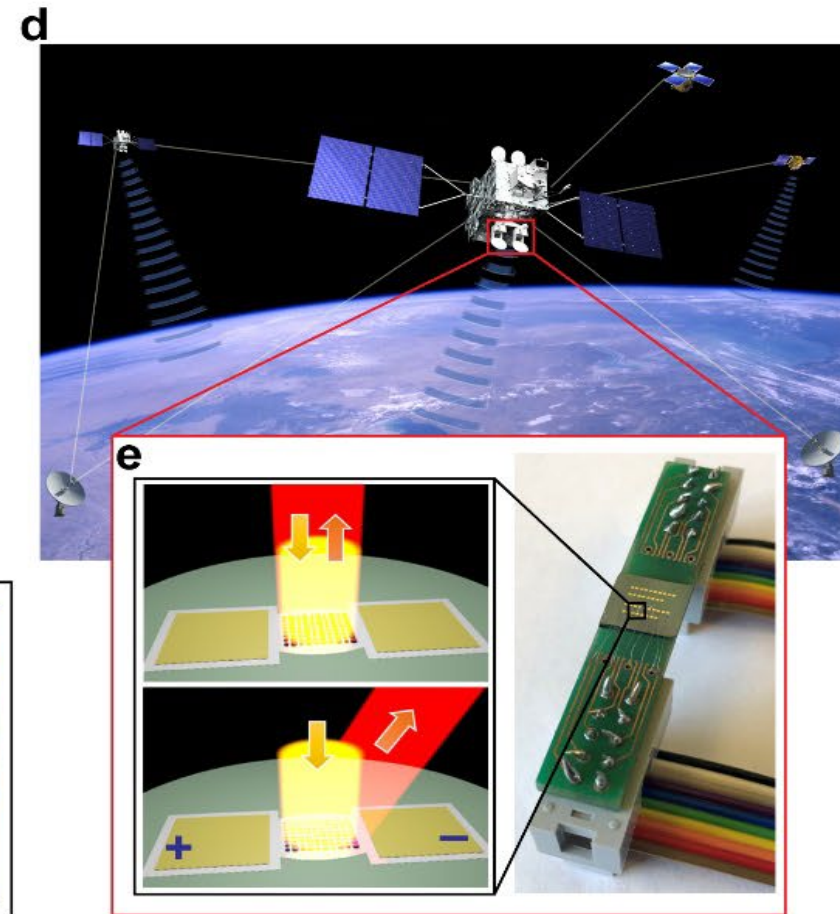


NASA Earth Missions

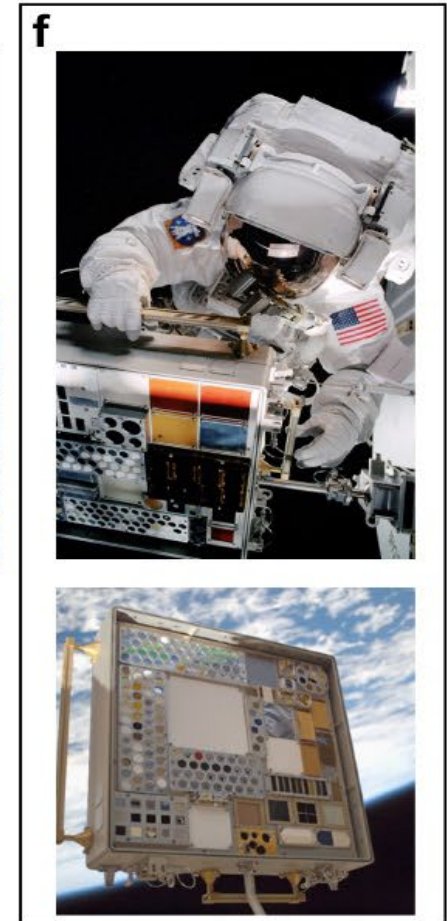
NASA mission- / program- driven scenarios and case studies



PCM tunable filter for remote sensing
Optica **7** (7), 746-754 (2020)

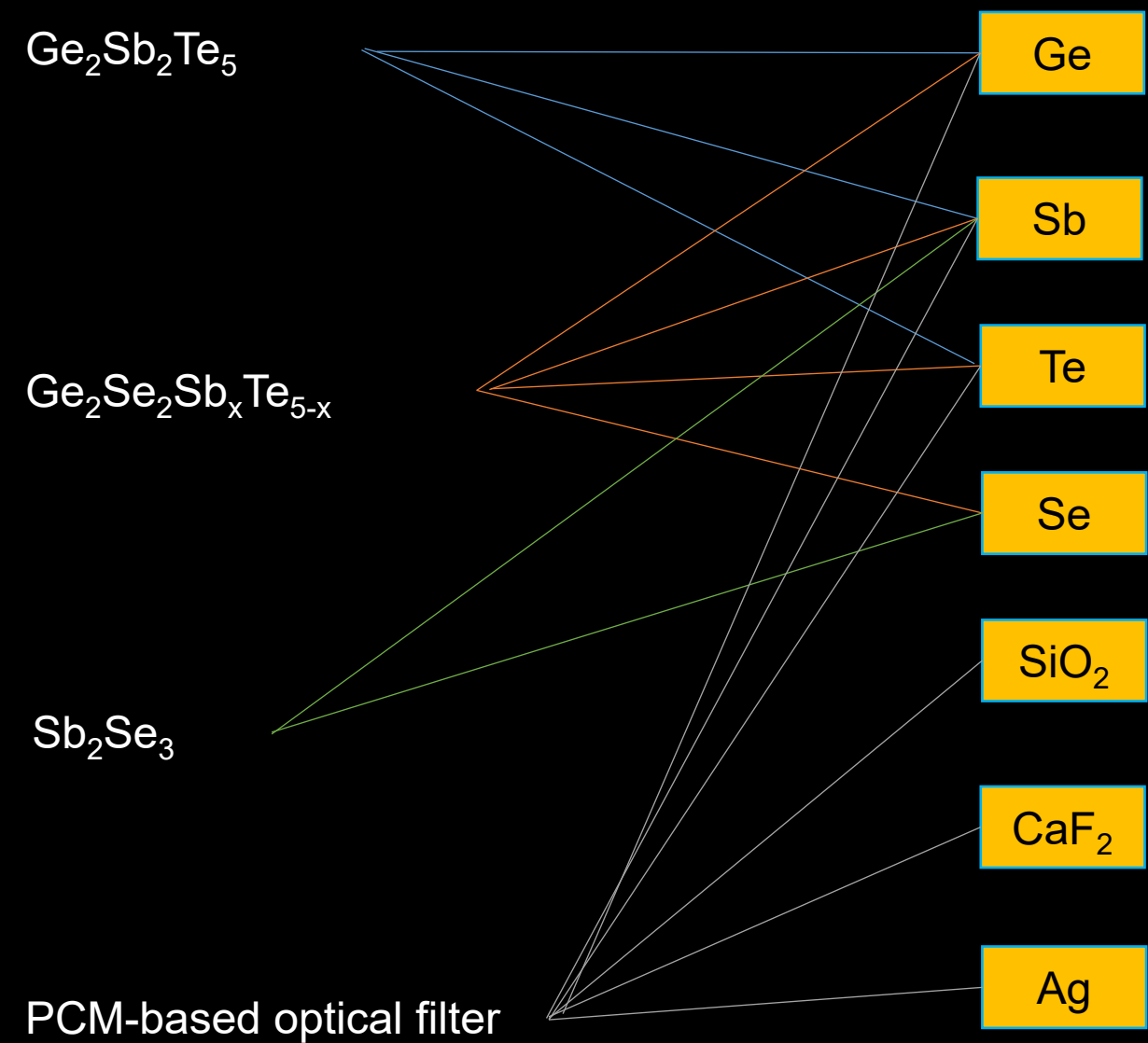
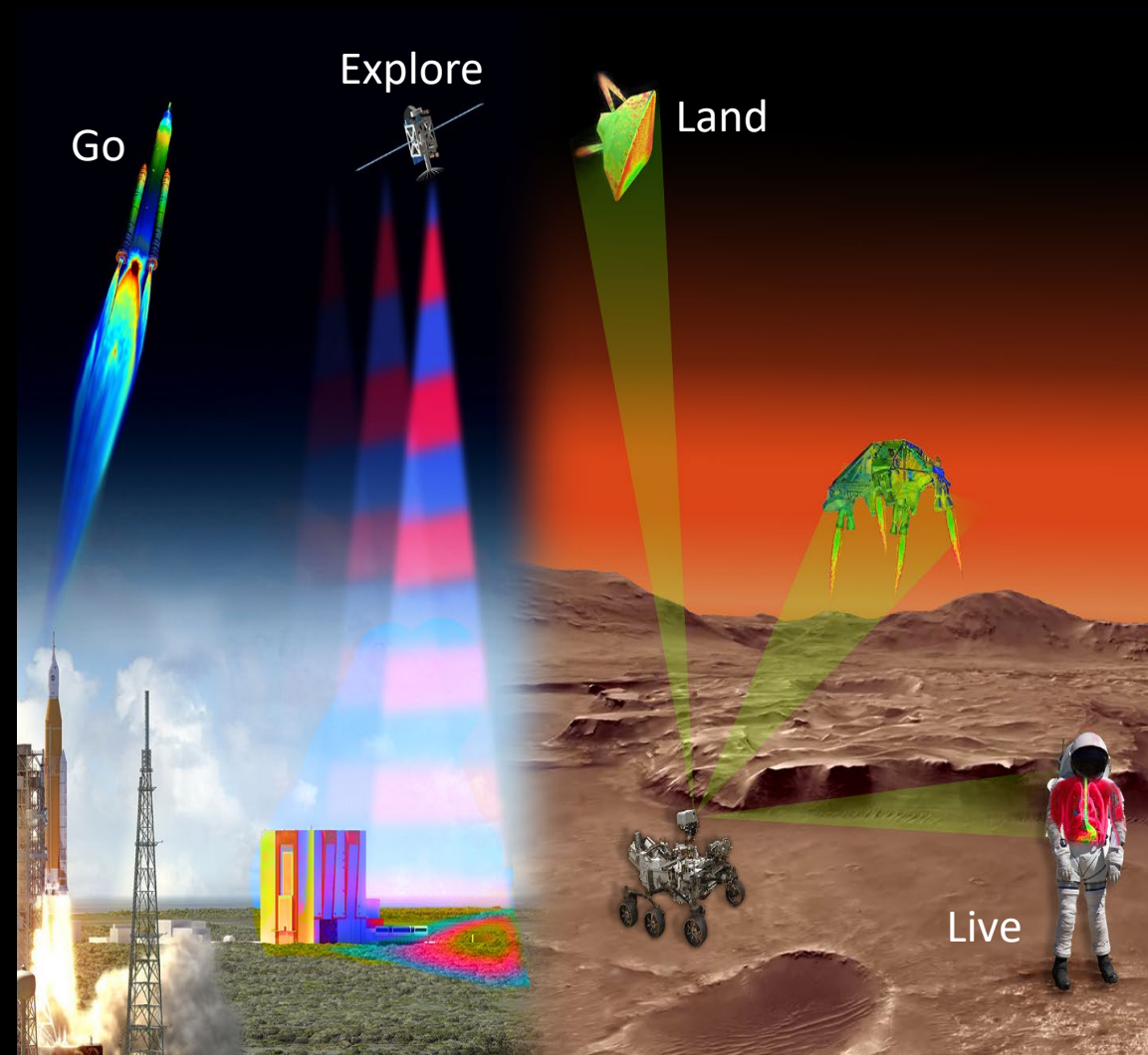


PCM reconfigurable optics for wavefront correction and beam steering
Nat. Commun. **12**, 1225 (2021).



PRAM in space
Nature Photon. **11**, 465-476 (2017).

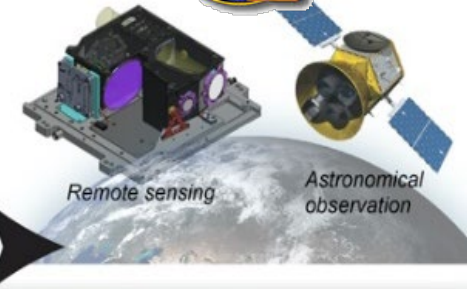
Summary: MISSE-14 opens door for multiple application (photonics & electronics) in space



Teams



- NASA LaRC (USA): Mr. Stephen Borg, Mr. Scott Bartram, and Mr. William Humphreys
- MIT (USA): Prof. Juejun Hu and Dr. Tian Gu
- Booz-Allen Hamilton (USA): Dr. Matthew Julian
- NASA LaRC: Dr. Amin Nehrir and Dr. Rory Barton-Grimley (Science mission)
- NASA LaRC: Dr. Jennifer Inman, Mr. Thomas Horvath, and Mr. Carey Scott (Space mission)
- University of Cambridge (UK): Dr. Calum Williams
- MIT & University of Washington (USA): Prof. Arka Majumdar



1966

PCM for
optical
storage
media

2017

P-ACTIVE starts at NASA
Langley Research Center

2019

I-SSPI Research team
Mission support team
New application collaborator (SAA)

2020

2021

MISSE -Space application team