

National Aeronautics and
Space Administration



Space-qualified Chalcogenide Materials through ISS MISSE Exposure

Hyun Jung Kim

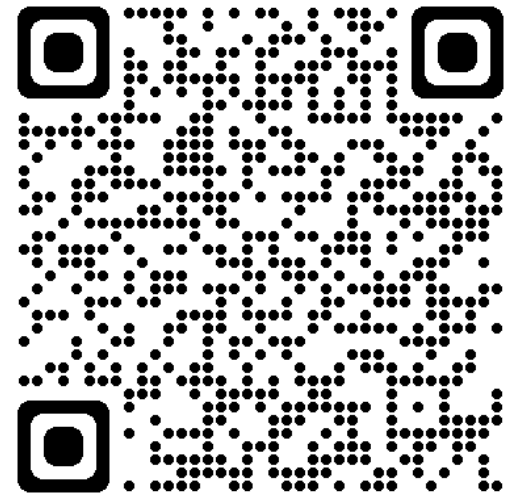
NASA Langley Research Center, Hampton VA 23681, USA

March 19th, 2024

NASA's Langley Research Center

HAMPTON, VIRGINIA

National Aeronautics and
Space Administration



[NASA Organization Structure](#) ²

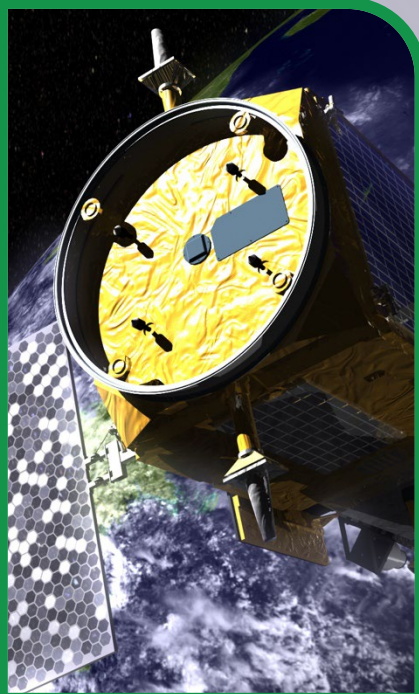
Our Role in NASA

National Aeronautics and
Space Administration



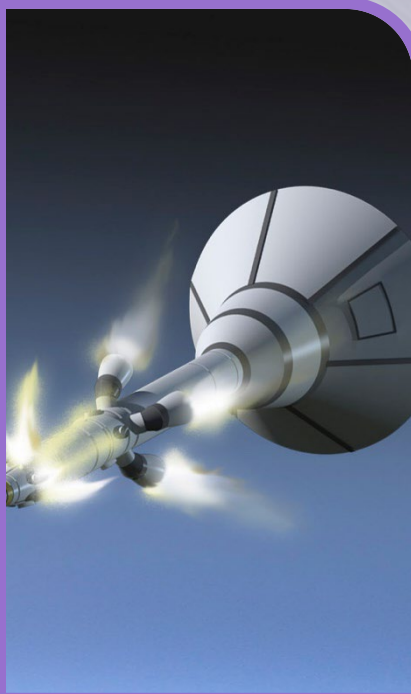
Langley Research Center

SCIENCE



Studying Earth and
worlds beyond

SPACE EXPLORATION



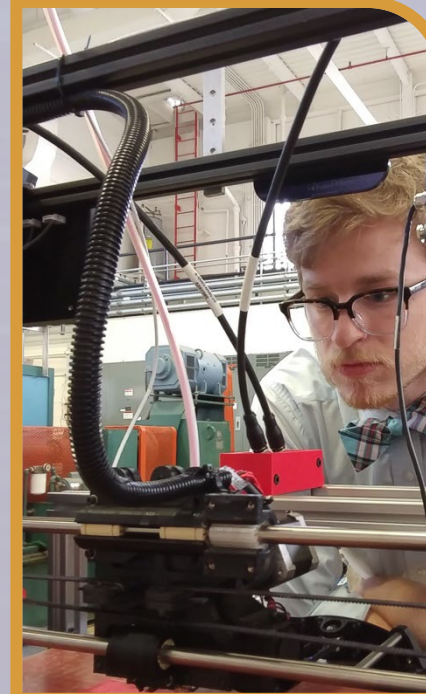
Tools to take us
from Moon to Mars

AERONAUTICS



Cleaner, faster,
safer air transport

TRANSFORMATION



Future of Langley's
work and workforce

STEM ENGAGEMENT



A new generation
of explorers

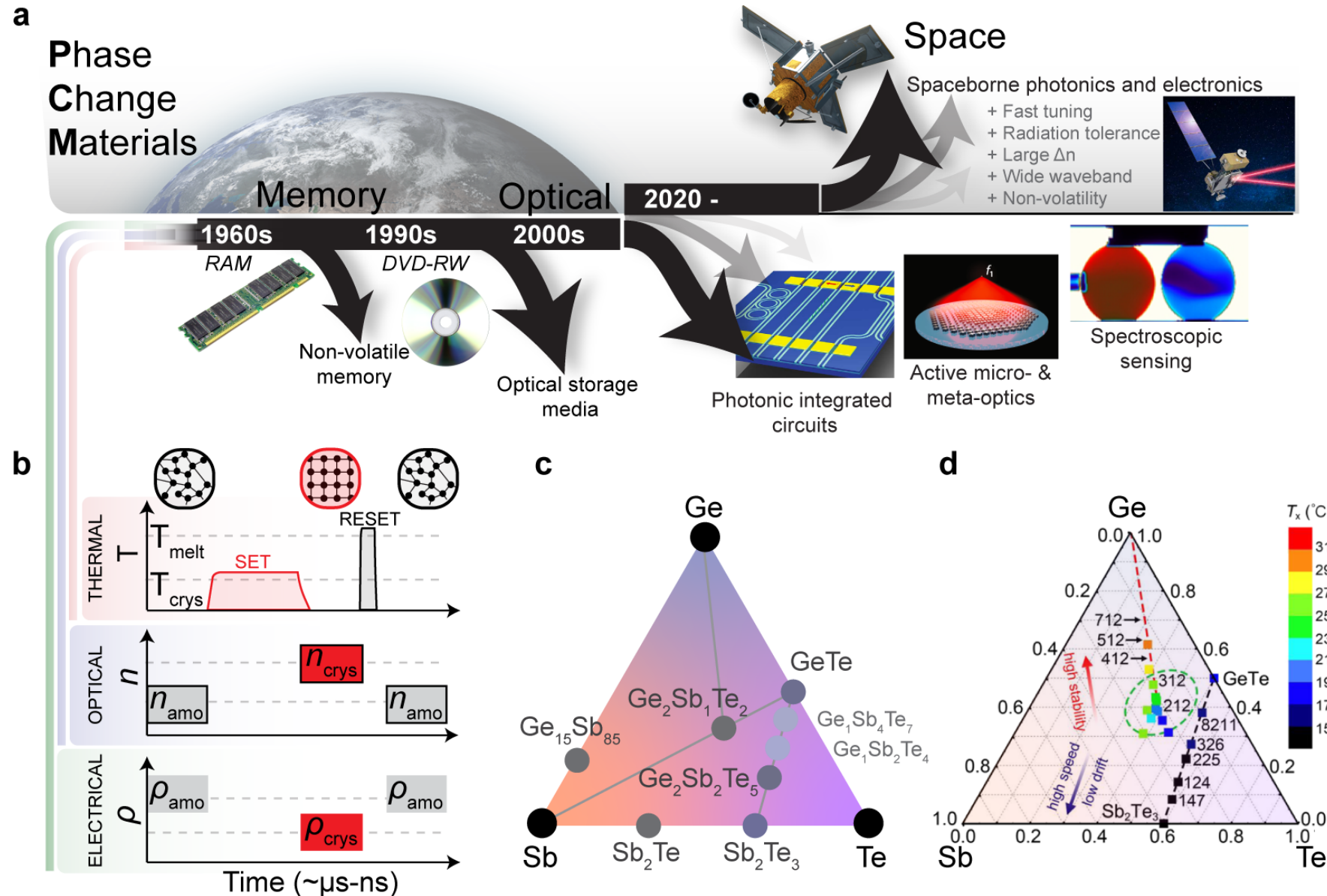
MISSE



- 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
- npj Microgravity “Versatile spaceborne photonics with chalcogenide phase-change materials” (2024)



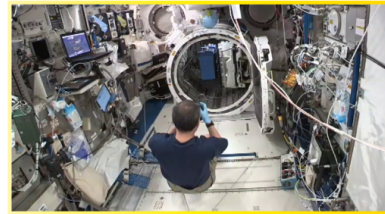
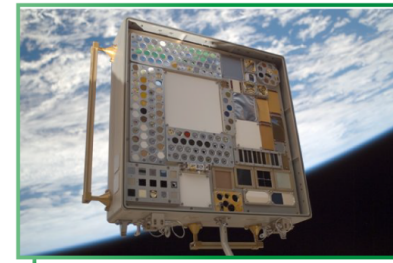
Why is NASA researching reconfigurable metasurfaces?



MISSE-14 PCM and PCM-based Tunable MWIR Filters



a



SPACE

EARTH

02.20.21
Launch

04.08.21
Unpack

04.25.21
Deployment
in orbit

06.21.21 - 12.6.21
Exposure &
monitoring
(148 days, 21 hrs, 11 mins)

Removal
from orbit
facility

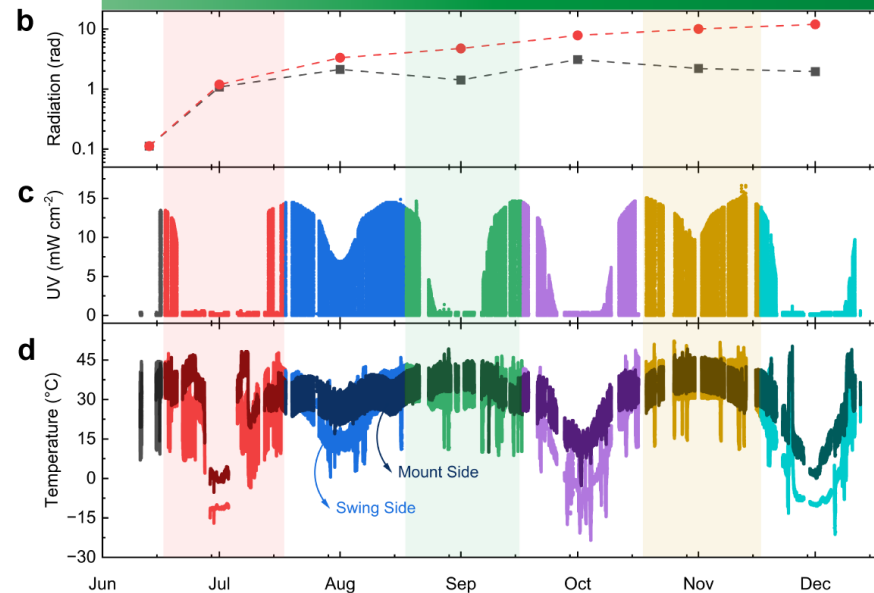
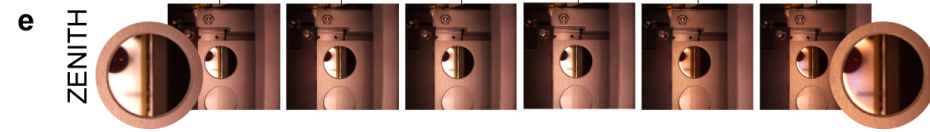
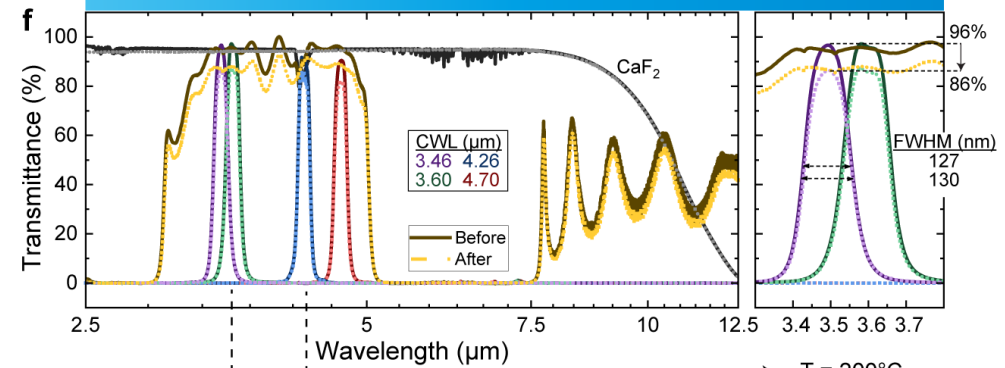
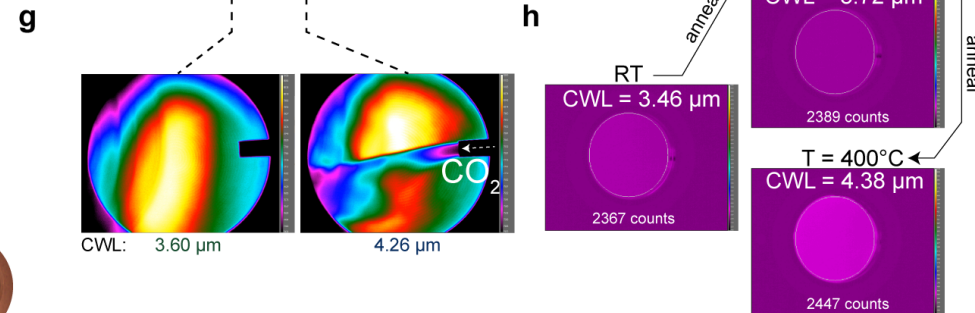
12.27.21
Return to
Earth

01.25.22

Retrieval &
Post-flight
characterization

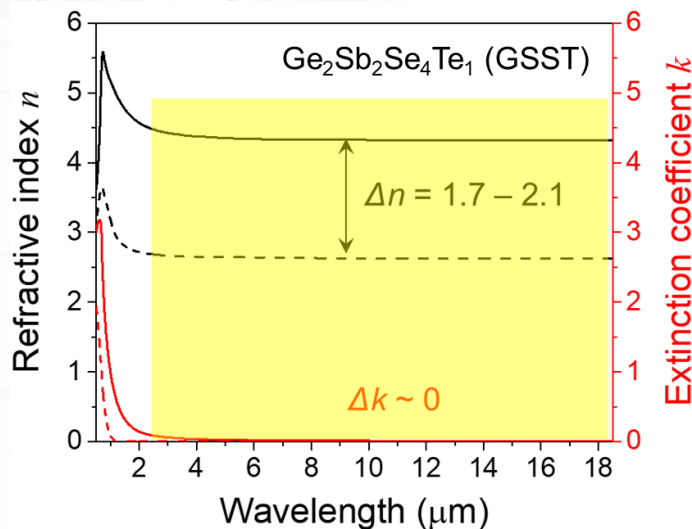


Pre-flight
characterization

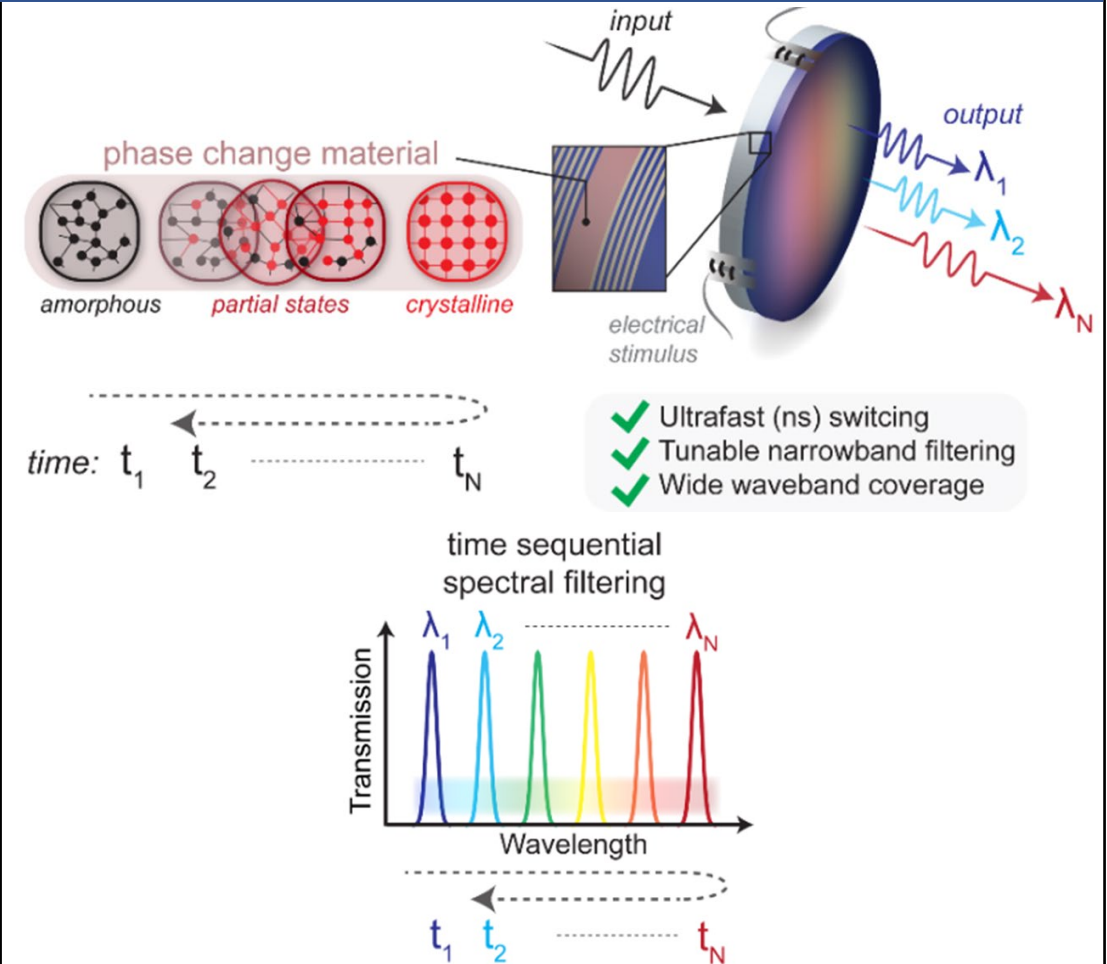


What are PCMs?

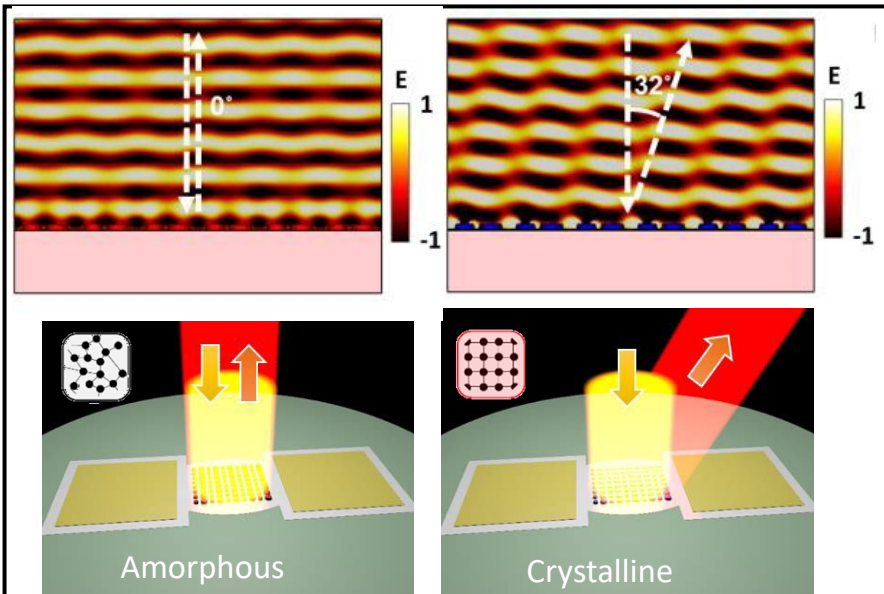
- In 1966, PCMs (i.e., $\text{Ge}_2\text{Sb}_2\text{Te}_5$ / GST) were developed for re-writable, non-volatile memory applications
- Memory recording between amorphous (0) and crystalline (1) phase transitions
- Reversible, linear, non-volatile phase transition
- PCMs exhibit an ultrafast refractive index modulation across the infrared or visible, depending on specific material
- From 2014, large refractive index contrast utilization in photonic devices (*Nature*, 511, 206-211 (2014))



PCM filter concept

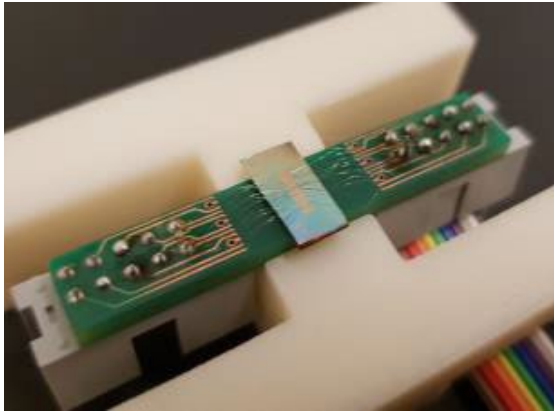
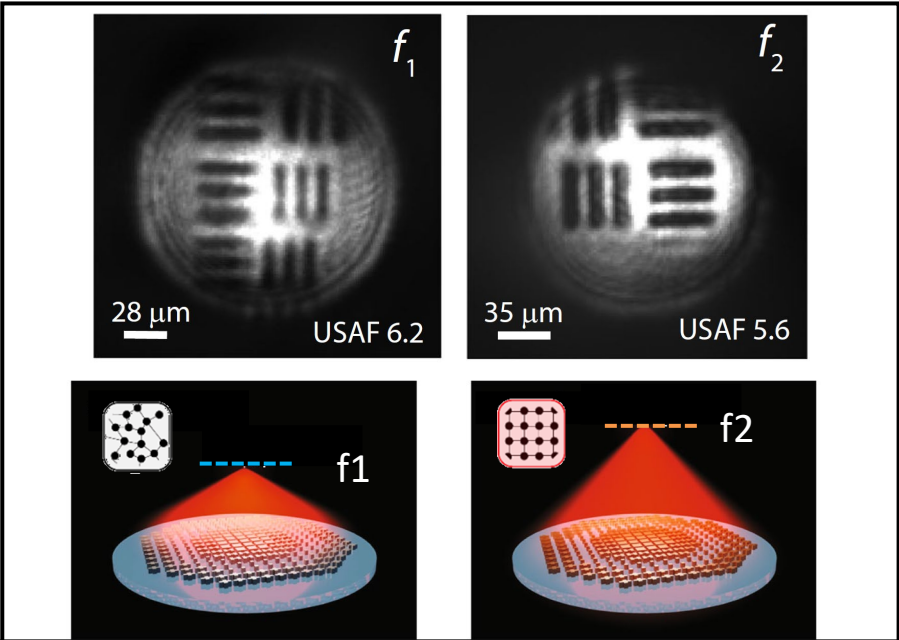


Reconfigurable Metasurface Optics using PCM



Nature Nano. 16(6), 1-6 (2021)

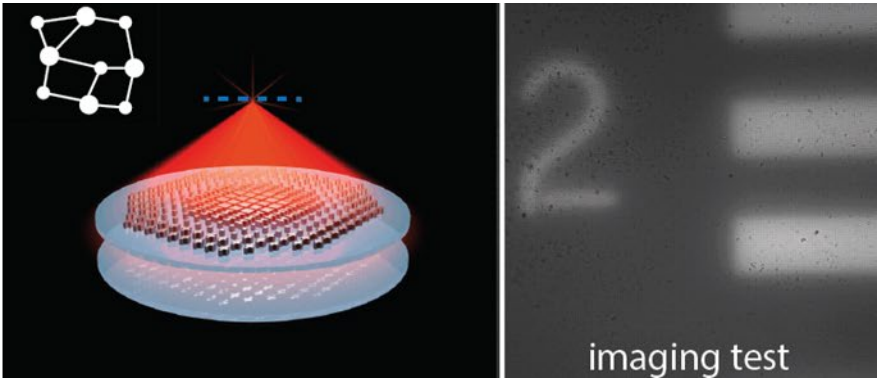
Packaged PROWESS



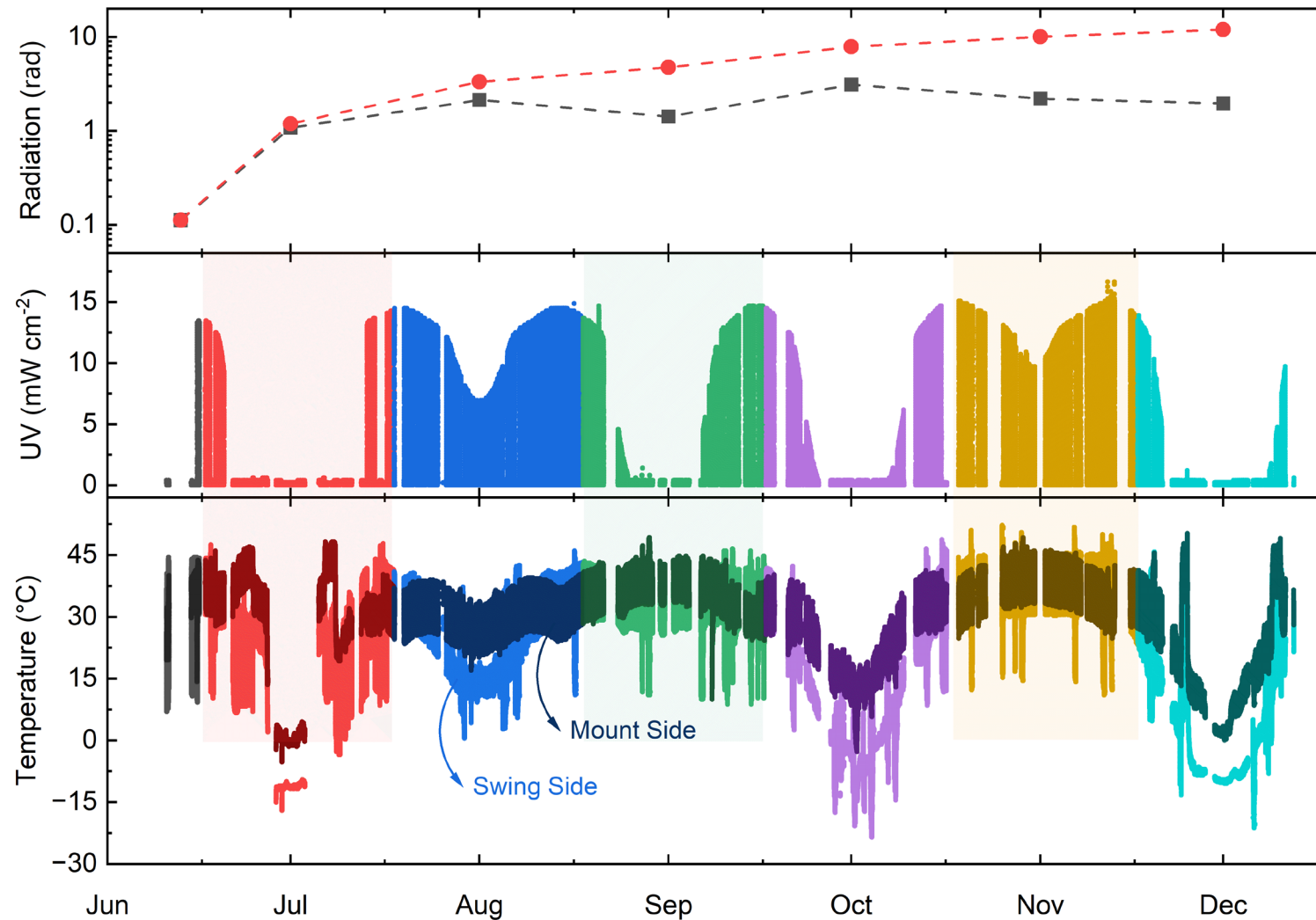
A **parfocal** zoom lens without moving parts

10x optical zoom

Adv. Opt. Mater. 10, 2200721 (2022)



Exposure Environment

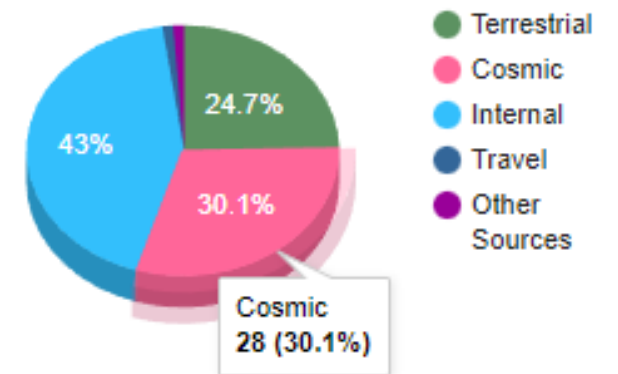


- The radiation level in ISS is >100X higher than earth annual exposure.

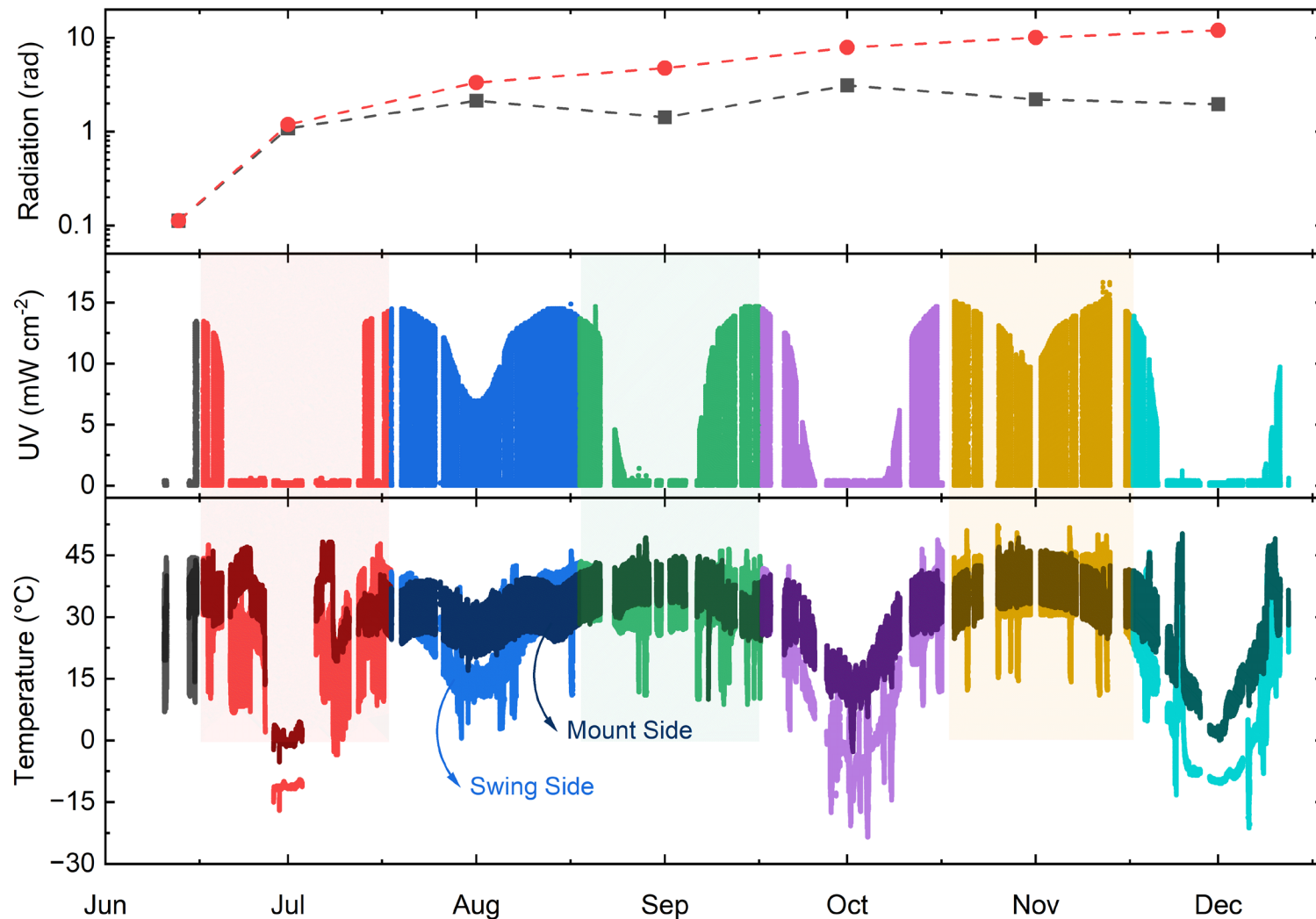
Lethal Radiation Level: >100 rads

Your total radiation dose per year is **93** mrem

Your Estimated Total Yearly Dose without Radon - 93 (mrem)



Exposure Environment



- The UV level is ~300X higher than the highest UV level measured on earth 0.05 mW/cm² [1].

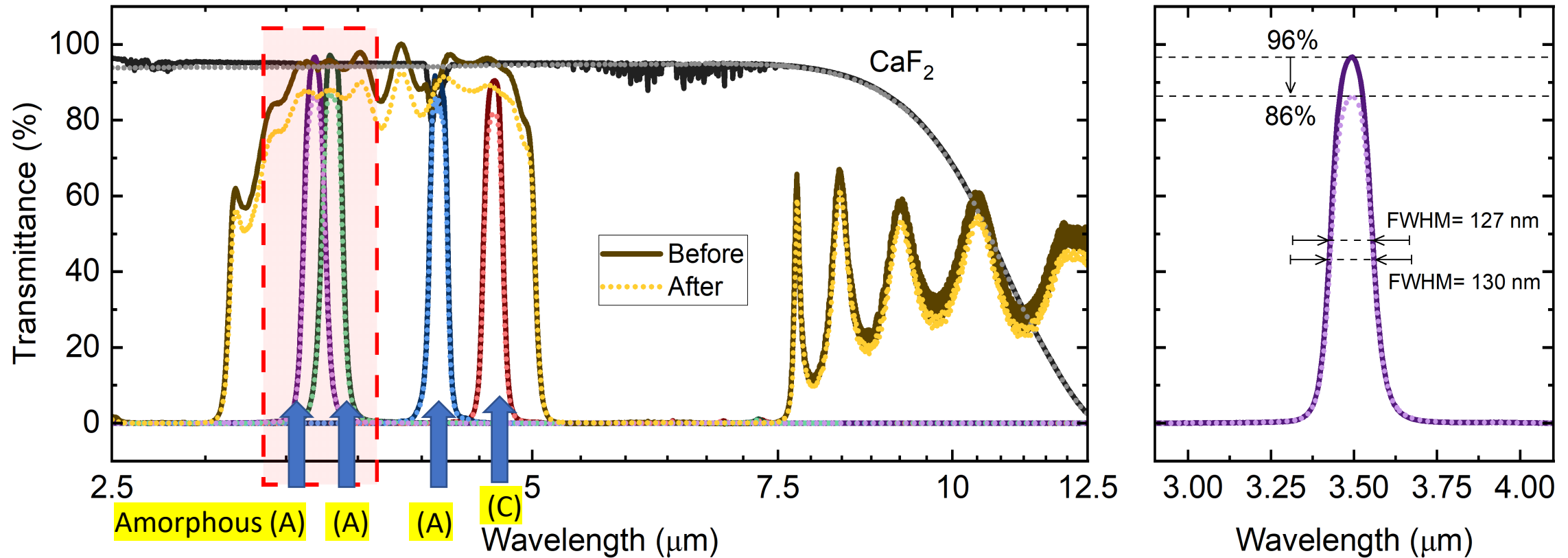
[1] Cordero, Raul R., et al. "The world's highest levels of surface UV." *Photochemical & Photobiological Sciences* 13.1 (2013): 70-81.

- The highest temperature difference recorded during the flight is from **-25 °C** to **+50 °C**.

Transmission Before vs. After Exposure



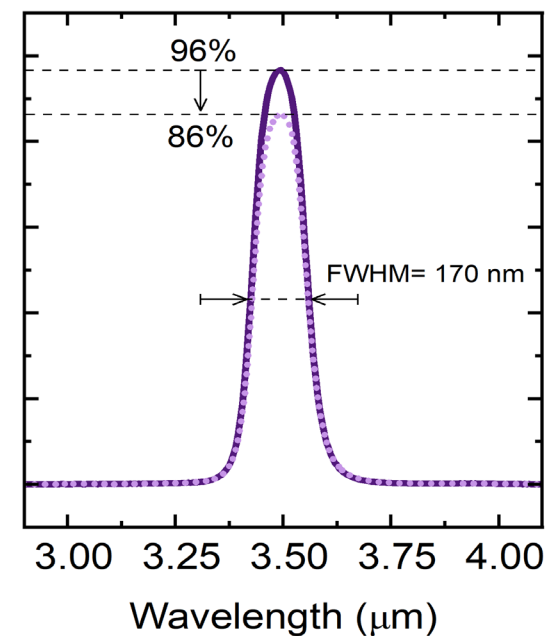
* The transmission of filters has dropped by 5-10% upon 6-month exposure to LEO.



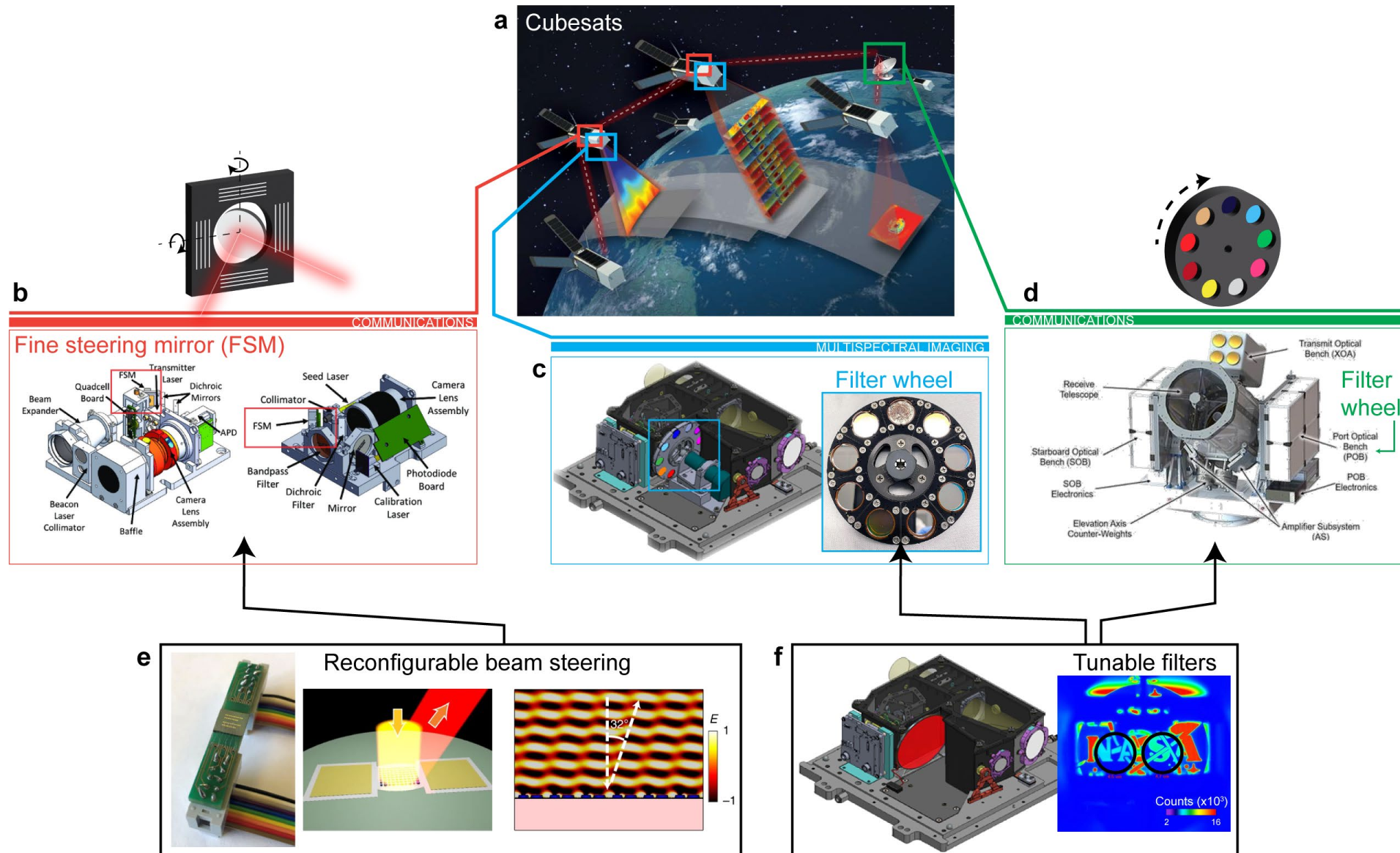
Fabry-Perot filters with different periodicity.

Ref: III-V semiconductor material for tunable Fabry-Perot filters for coarse and dense WDM systems

- Different chalcogenide-based PCM (GST, GSST, SbS) are sent to ISS for exposure to LEO environment.
- Relatively extreme environment is recorded for the 6-month period that the specimens were in space:
 - ✓ **Nearly 75 °C temperature fluctuations**
 - ✓ **100X higher Radiation**
 - ✓ **300X higher UV exposure**
- Visual variation is observed in a few specimens after return to earth, mostly those exposed to Zenith orientation.
- Transmission of filters is reduced by 5 to 10%.

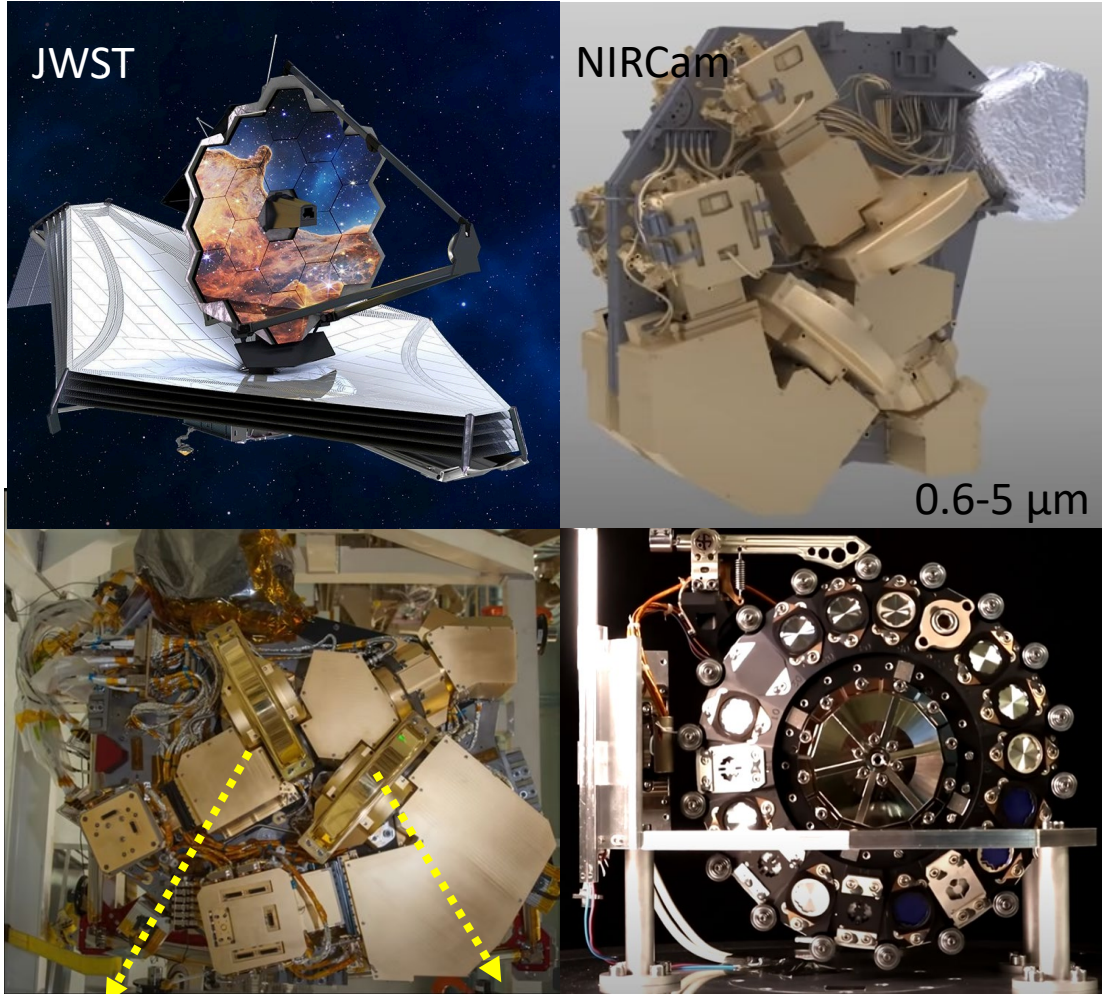


Spaceborne application examples: sub-systems in CubeSats



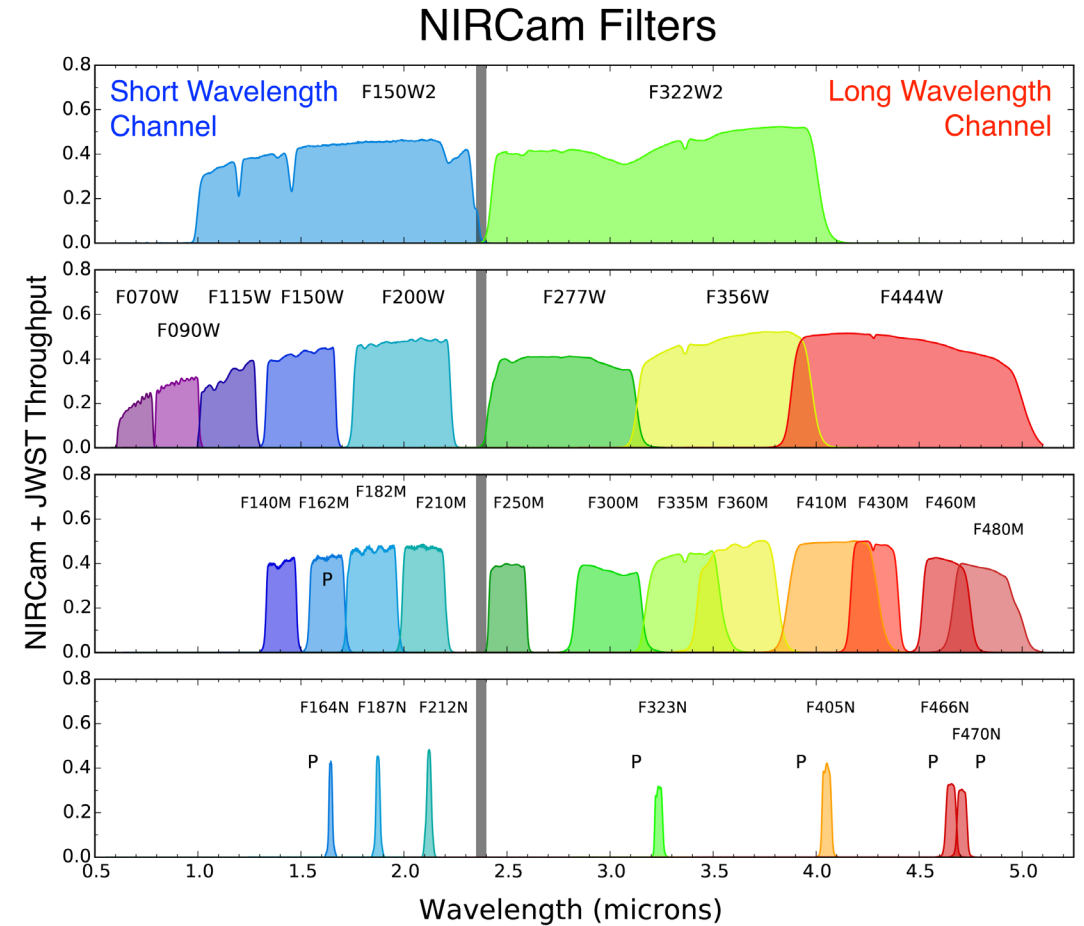
Tunable Optics for Space Explorations

<https://www.youtube.com/watch?v=MzWfUK0yvdY>



Long Wavelength
Filter Wheel

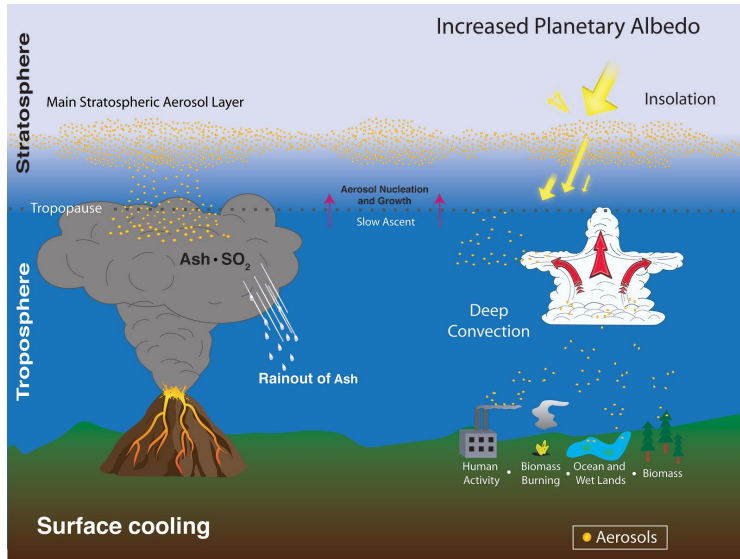
Short Wavelength
Filter Wheel



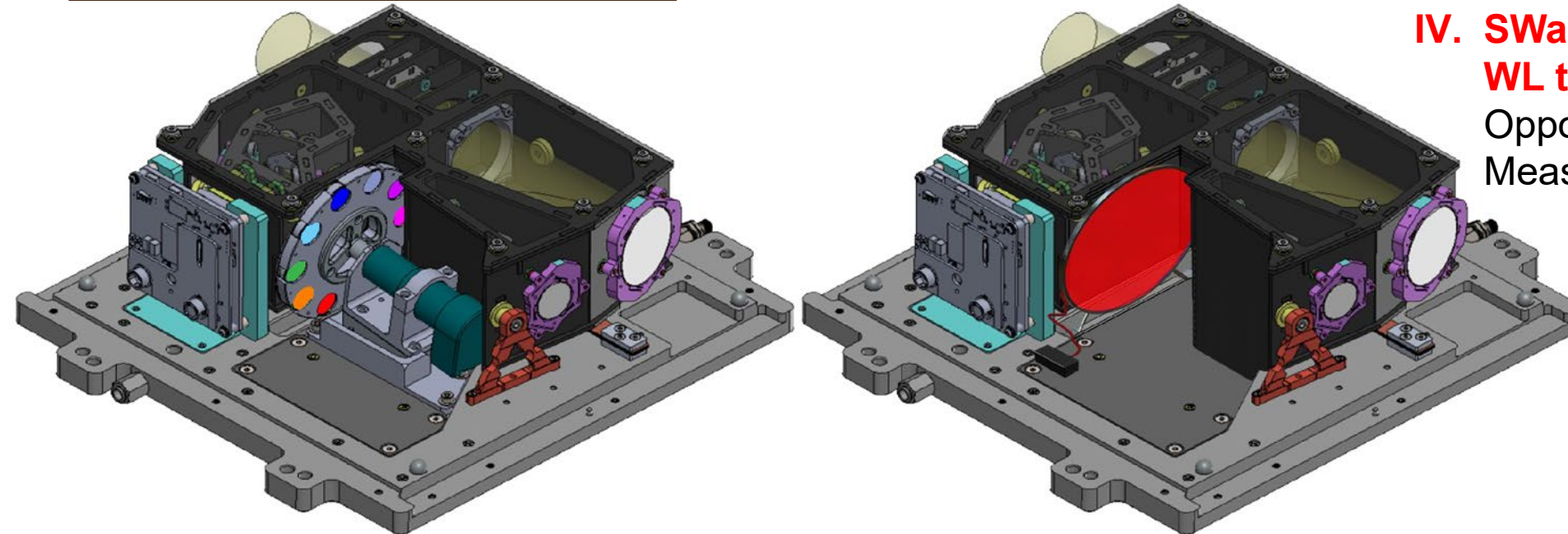
NASA LIDAR mission



<https://www.nasa.gov/sage3-iss>



- I. SAGE precisely measuring the constituents that influence the balance of our atmosphere
- II. SAGE-IV was developed at 1/10th the cost of SAGE-III
- III. 6U Cubesats and Smallsats open opportunities for Rideshare launches
- IV. **SWaP + No moving part + More WL tunability** = More Opportunity = More Measurements



15-years NASA Professional & Personal Growth



Space **(functional)** Materials & **(sensors)** in Scientific Payload

Independent researcher, PI, PM, Engineer, Mission support team member, Mentor, and Educator

KAIST

2009

2010

2011

2012

2013

2014

2015

2016

2017

2018

2019

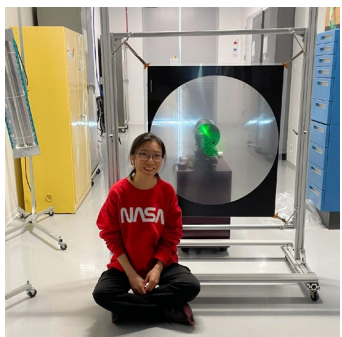
2020

2021

2022

2023

NASA



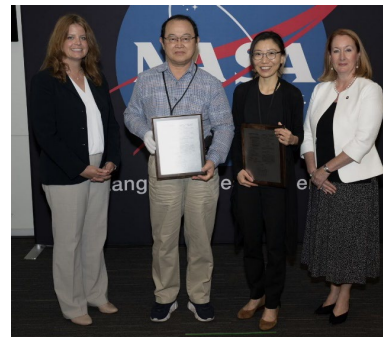
AIAA young engineer award



NASA director award



NASA best paper awards



NASA patent awards



NASA exceptional technology achievement medal



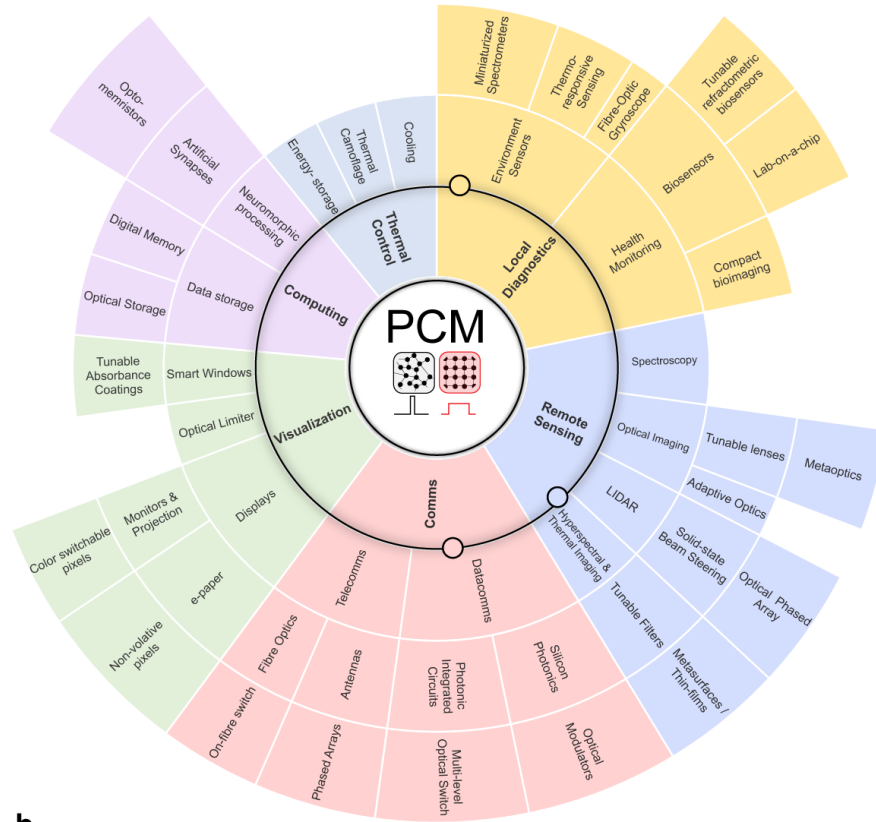
- ✓ 28 mentoring
- ✓ 16 projects (\$3.4M/ 43억 원)
- ✓ 13 patents & 23 inventions
- ✓ 16 awards (AIAA EOY, 2024)
- ✓ 120 international talks

Back-up slides

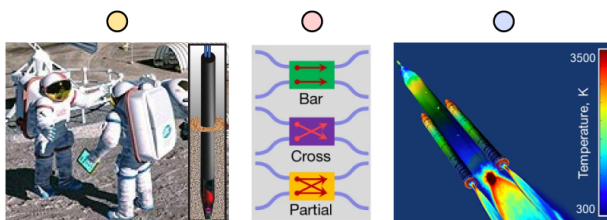
PCM-based photonics for spaceborne applications



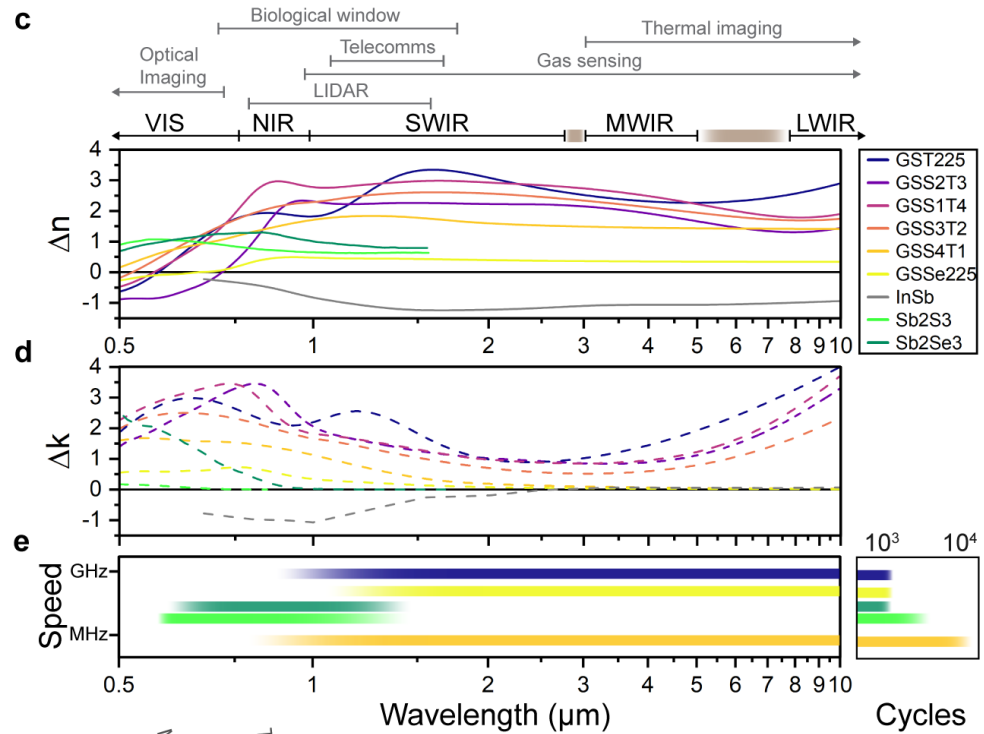
a



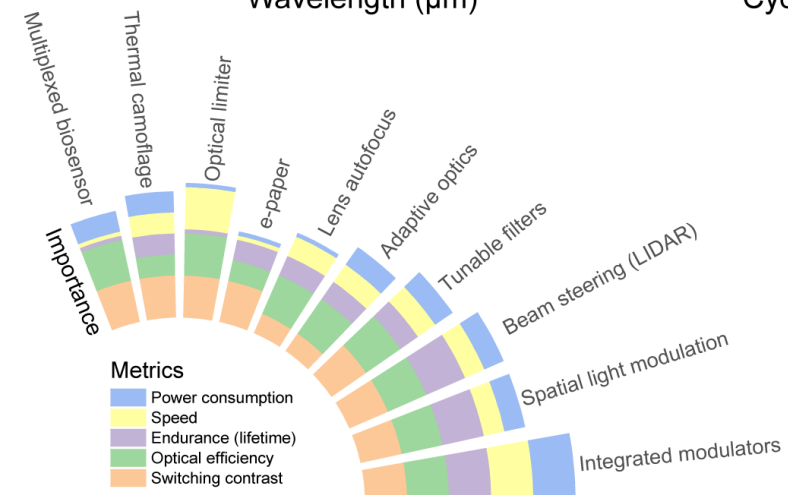
b



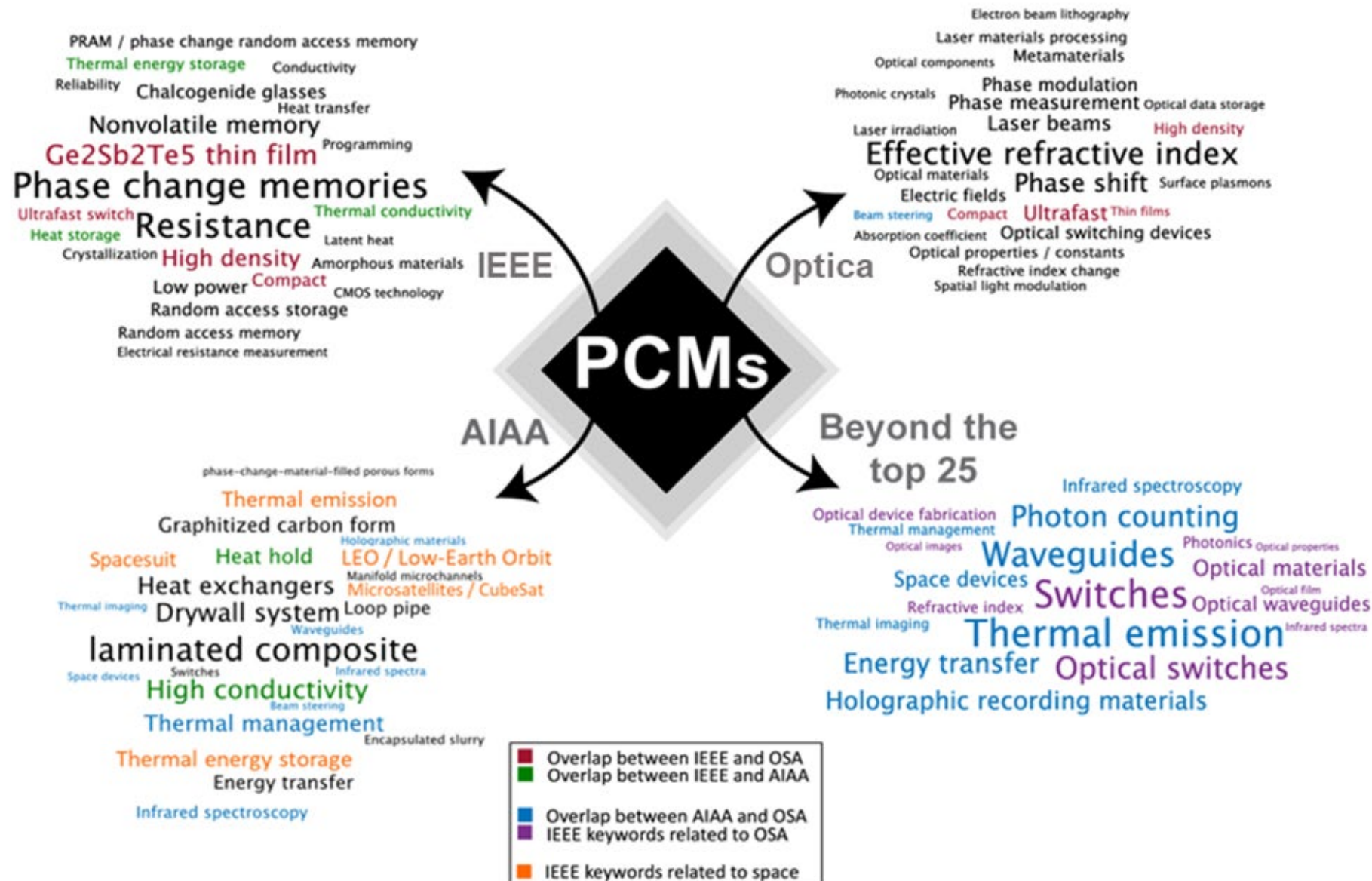
c



f



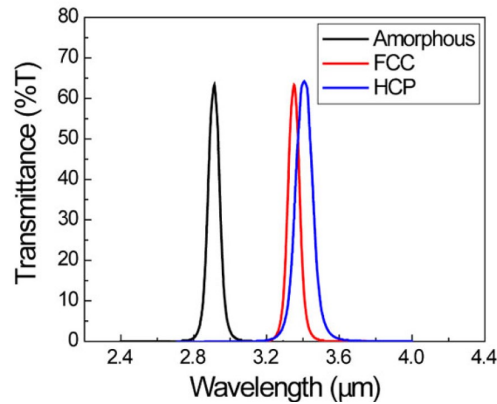
Evidence of PCM research can, and should, expand from terrestrial to space applications from keywords searching



Technology Development Progress (H. J. Kim *et al.*)



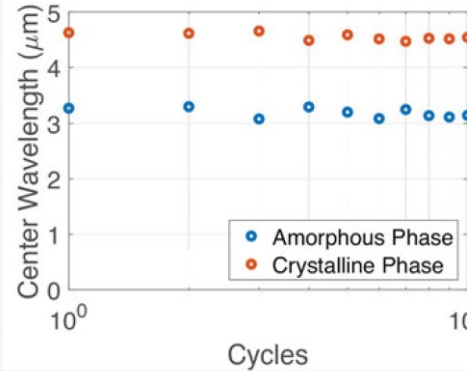
P-ACTIVE tunability & gas sensing



Optica **7**(7) 746 (2020)

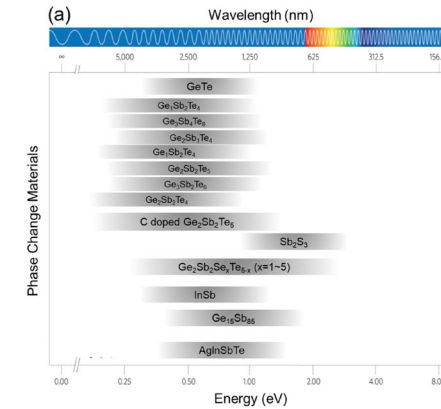
Optics Express **28**(7), 10583 (2020)

Reliability test



Optical Eng. **60**(8) (2020)

PCM-net database

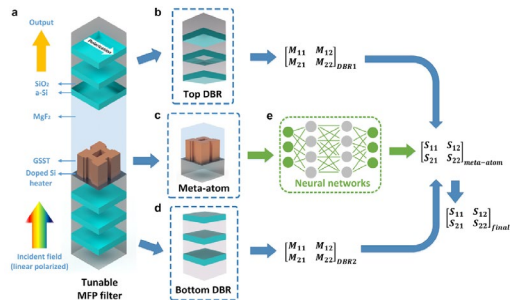


J. Phys. Photo. **3**, 024008 (2021)



ACS, highlight (2022)

DNN design

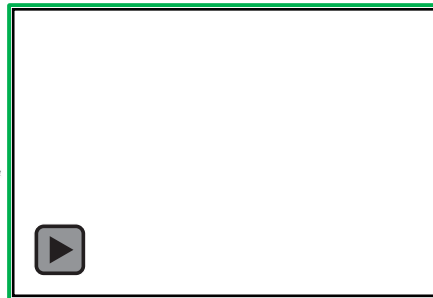


Nanophotonics **11**(17), 4149 (2022)

NASA/TP-20220019141



P-ACTIVE Project Report



NASA TP-20220019141(2022)



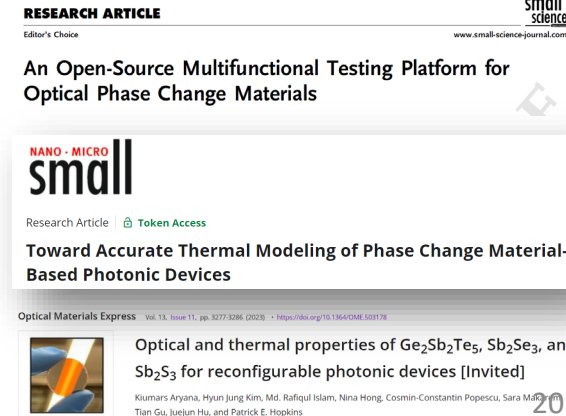
A Multi-Spectral Imaging Pyrometer Patent *Applica.*(2022)

Vision to sub-system



Nature Photonics **17**(48) (2023)

2023 -



Optical Materials Express Vol. 13, Issue 11, pp. 3277-3286 (2023) - <https://doi.org/10.1364/OME.503178>

MISSE-14



MISSE-21 “Electrically reconfigurable metafilter” (March 2025)

