CHAPS-D: The Compact Hyperspectral Air Pollution Sensor–Demonstrator

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NASA/GSFC = NASA/Goddard Space Flight Center, Greenbelt, Maryland, USA
TNO = The Netherlands Organization for Applied Scientific Research, Delft, The Netherlands
KNMI = Royal Netherlands Meteorological Institute and University of Technology Delft, The Netherlands
NCAR = National Center for Atmospheric Research, Boulder, Colorado, USA

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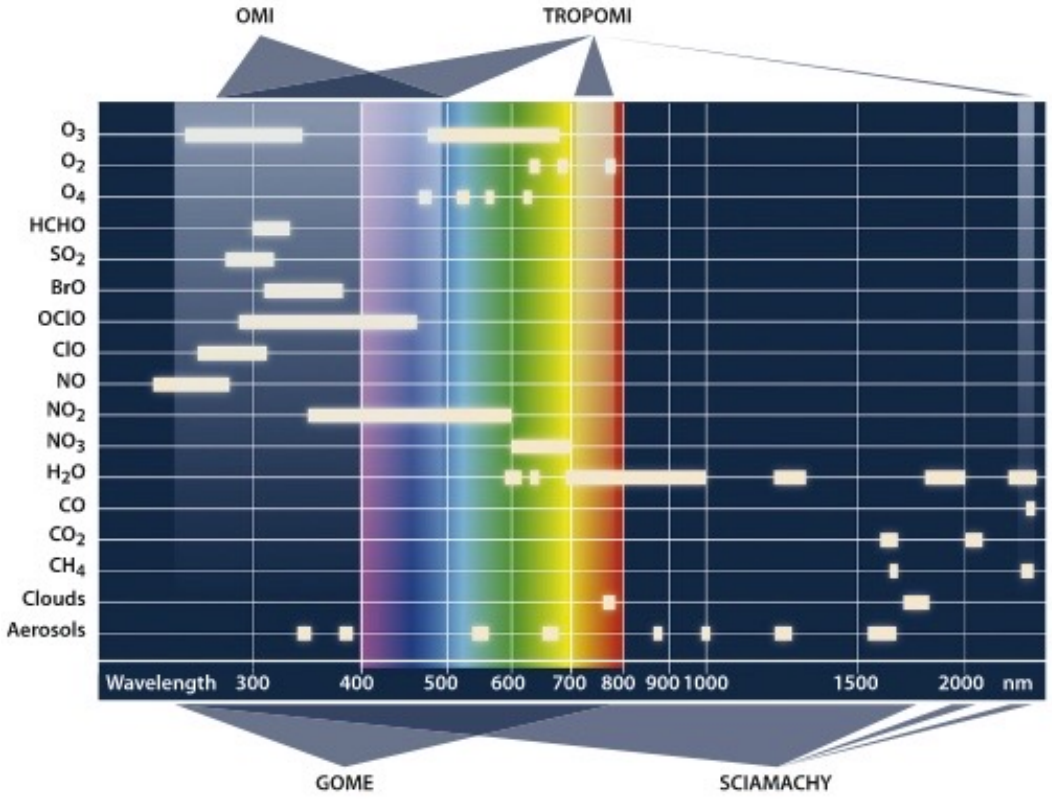
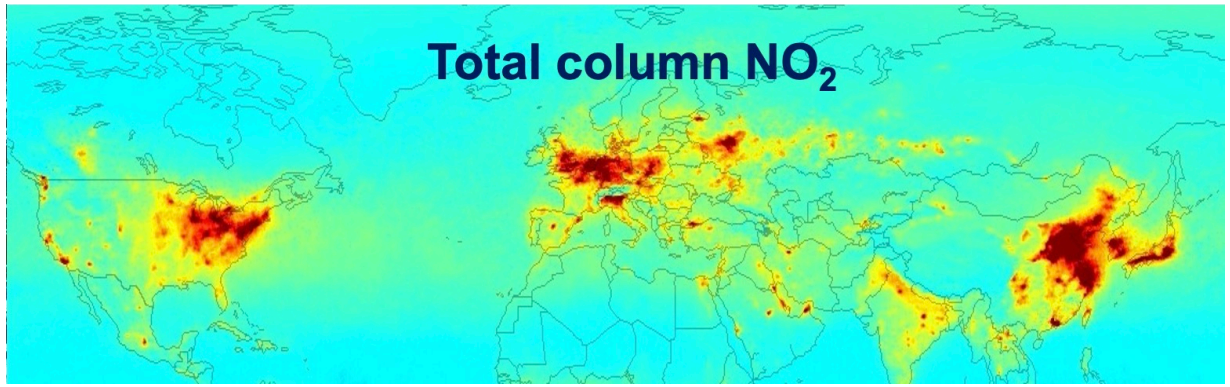
Remote sensing of trace gases from space: Hyperspectral imaging

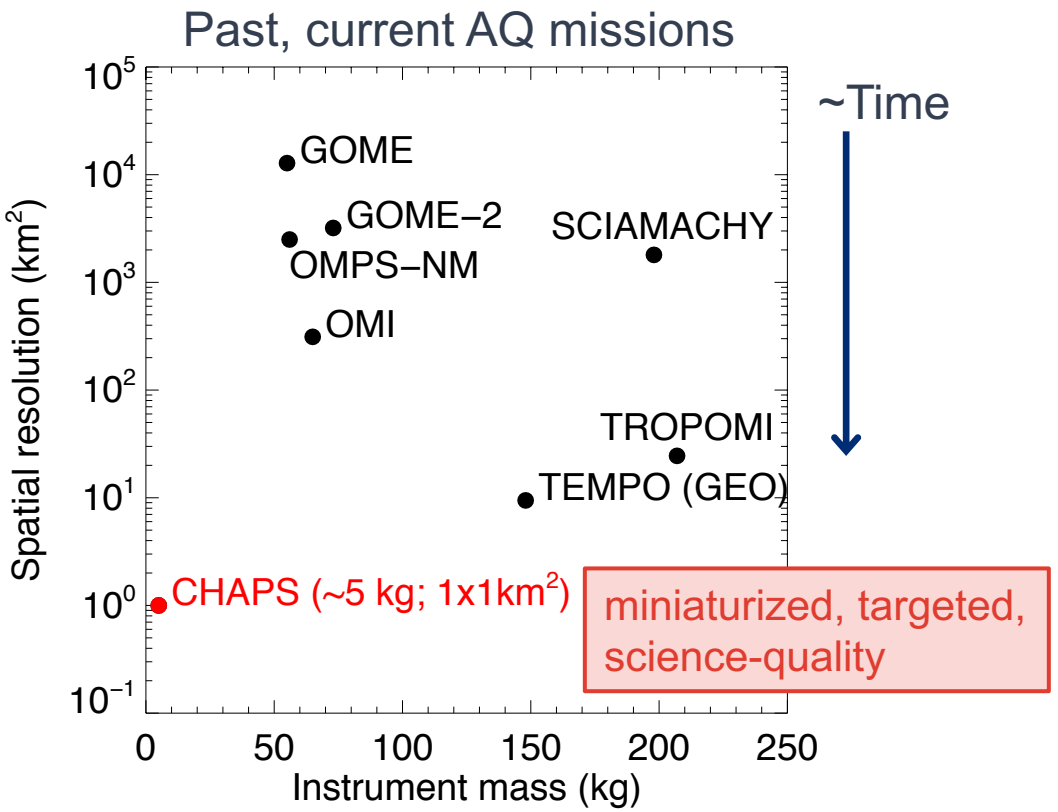


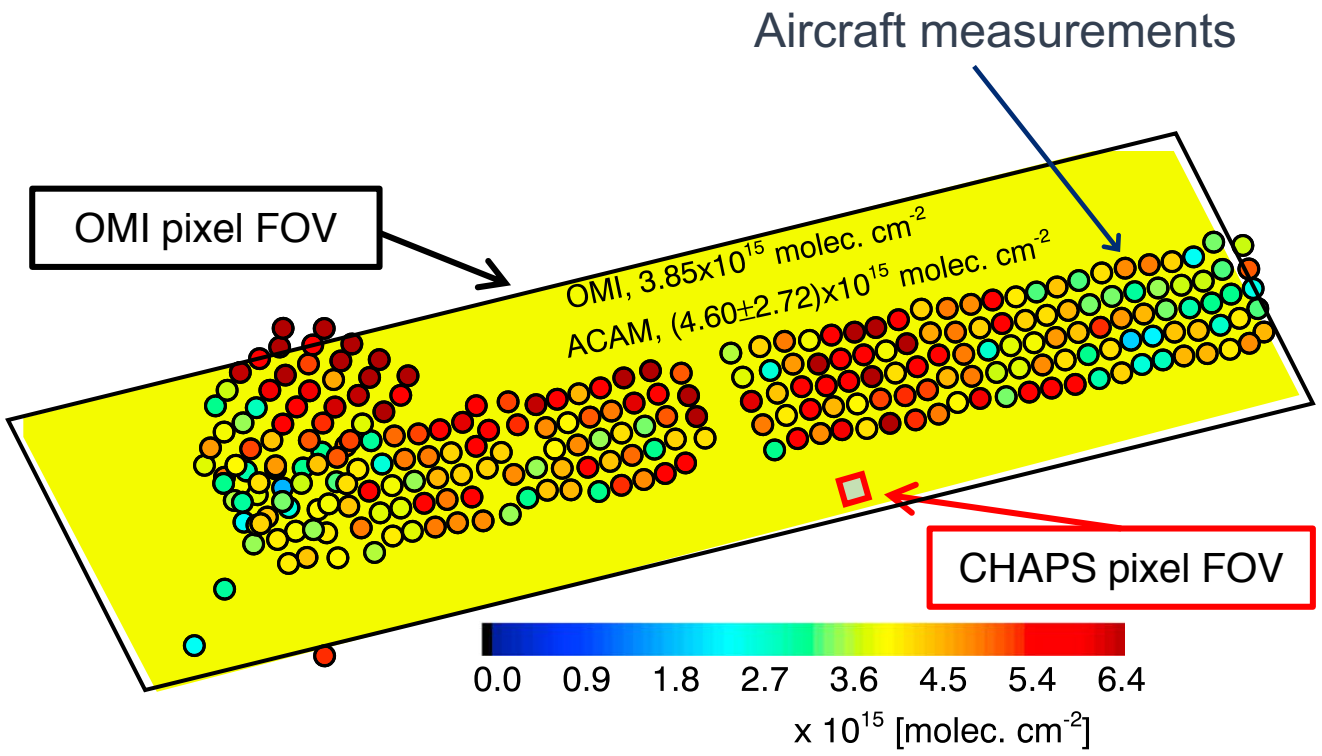
[*Veefkind et al.*, 2012]



- Air pollution has negative impact on human and ecological health
- Changes in pollution caused by changes in energy usage, technology, regulation, and climate change
- NO_2 and CO_2 anthropogenic emissions are correlated
- Air pollution disparities reflect racial, ethnic, and income inequality in the US
- Need for high-spatially and -temporally resolved measurements of air pollution

Smaller is (sometimes) better

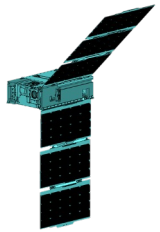




derived from *Lamsal et al.* [2017]

Does some of what OMI, TROPOMI do, in a small package

Aura, 2003



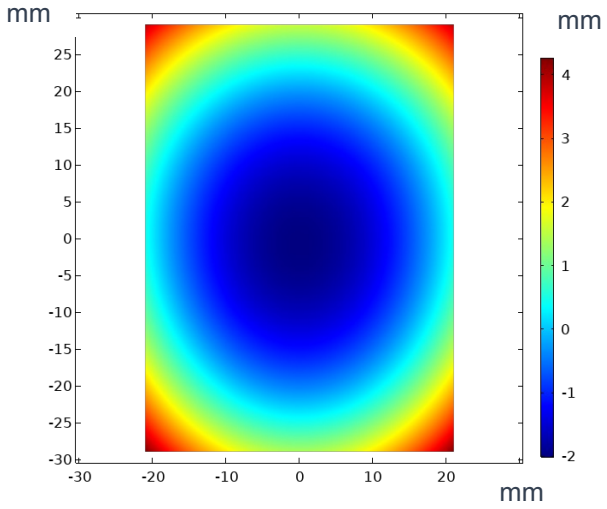
CHAPS

(very roughly to scale)

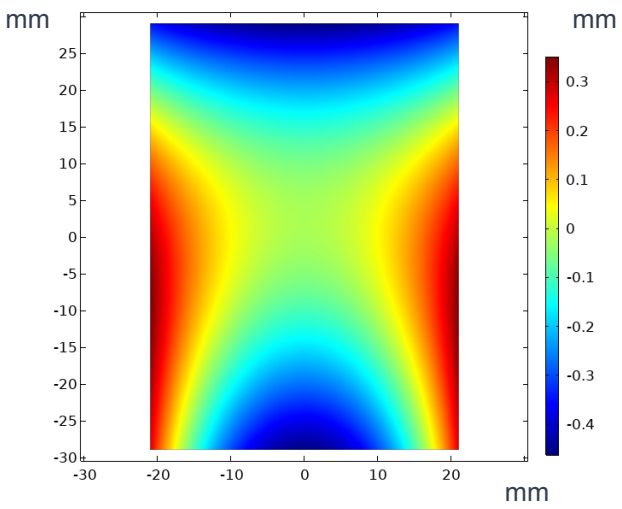
Freeform optics enables miniaturization

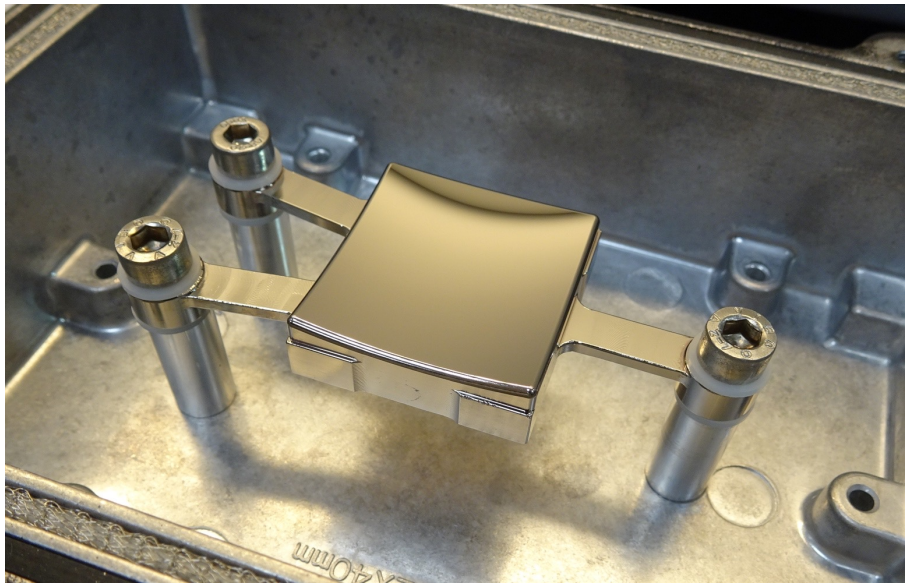
- Freeform optics: *An optical surface that lacks translational or rotational symmetry*
- Superior optical aberration correction, compared to spherical and aspherical alternatives
- Reduces size while maintaining performance

Imager mirror #3: **Surface shape**



Imager mirror #3: **Deviations from parabola**

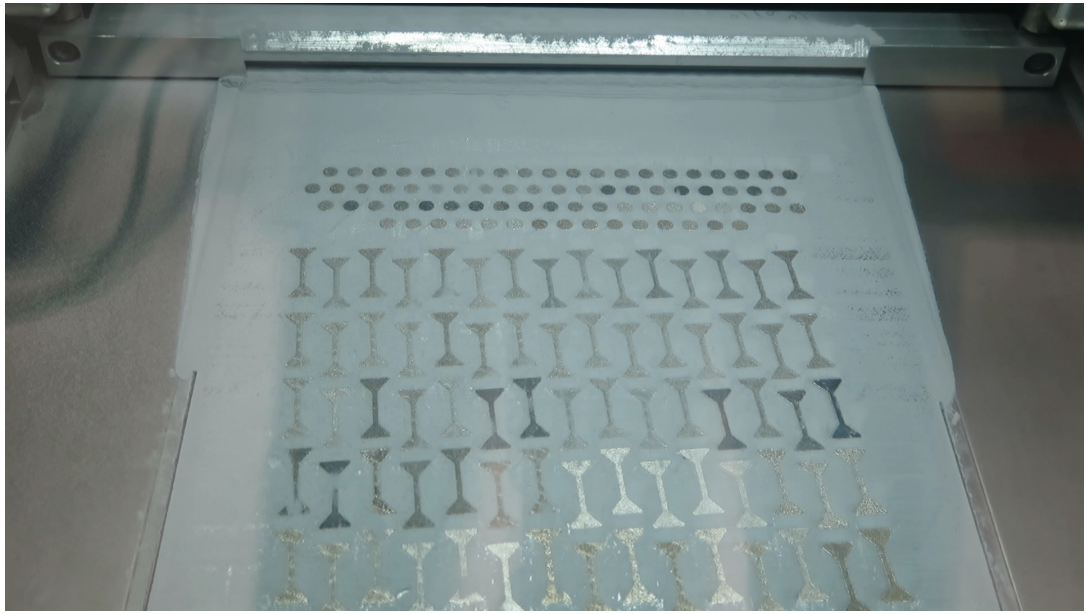




CHAPS-D imager mirror #2

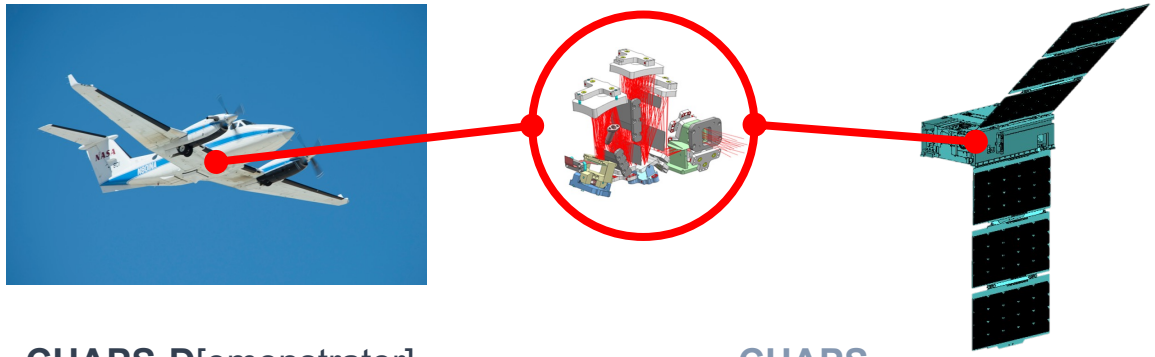
Additive manufacturing (3-D printing) provides a number of potential advantages

- Make things that are hard (or impossible) using traditional manufacturing
- Use topology optimization for mass, thermal, vibration, and (additive) manufacturability
- Internal baffling fine structure (critical for stray light control) is very amenable to AM
- Reduces complexity of housing (idea: AM entire mechanical structure and light baffling)
- Reduces manufacturing time and cost of future instruments



renishaw.com

CHAPS-D IIP is an airborne CHAPS demonstration



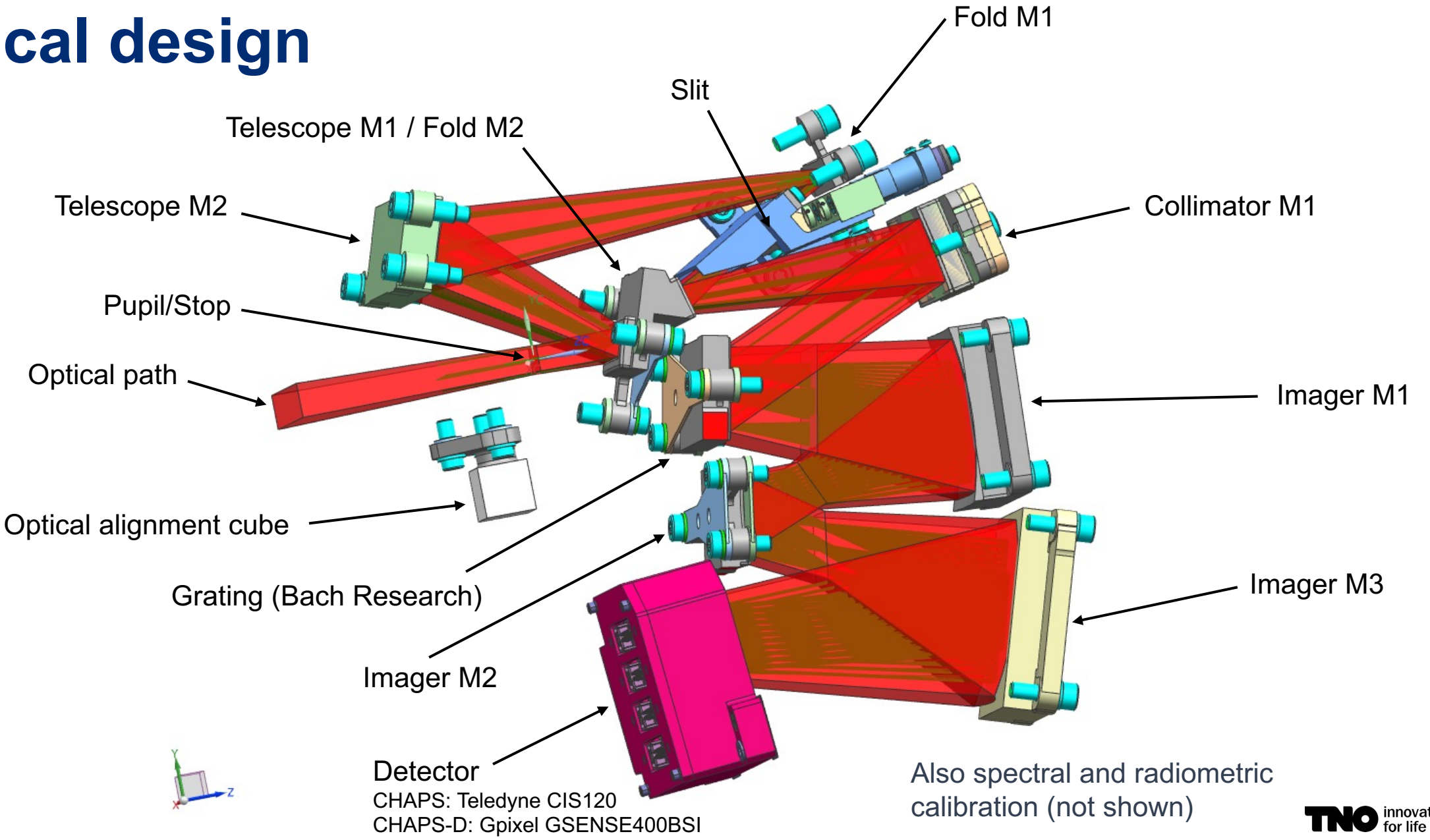
CHAPS-D[emonstrator]
(this IIP)
Altitude ~8 km
Spatial resolution ~20 m

CHAPS
(potential future project)
Altitude 400–600 km
Spatial resolution ~1 km

- Design, fabricate, calibrate, and test prototype CHAPS-D, conforming to 6U constraints and space requirements, where reasonable
- Conduct ground-based, zenith-sky measurements as a real-world test of the instrument under controllable conditions and ambient pollution at suburban location NASA/GSFC in Maryland
- Perform aircraft demonstration, making nadir observations of tropospheric pollution
- Retrieve tropospheric NO_2* vertical column density using well-established techniques, demonstrating end-to-end capability
- Compare retrieved NO_2* (and others) with correlative measurements on the ground, potentially from another instrument co-manifested on the aircraft and operational satellite products from OMI and TROPOMI
- Use lessons learned to improve the CHAPS design and define the spacecraft interface requirements

*Also SO_2, ozone, formaldehyde, glyoxal, clouds

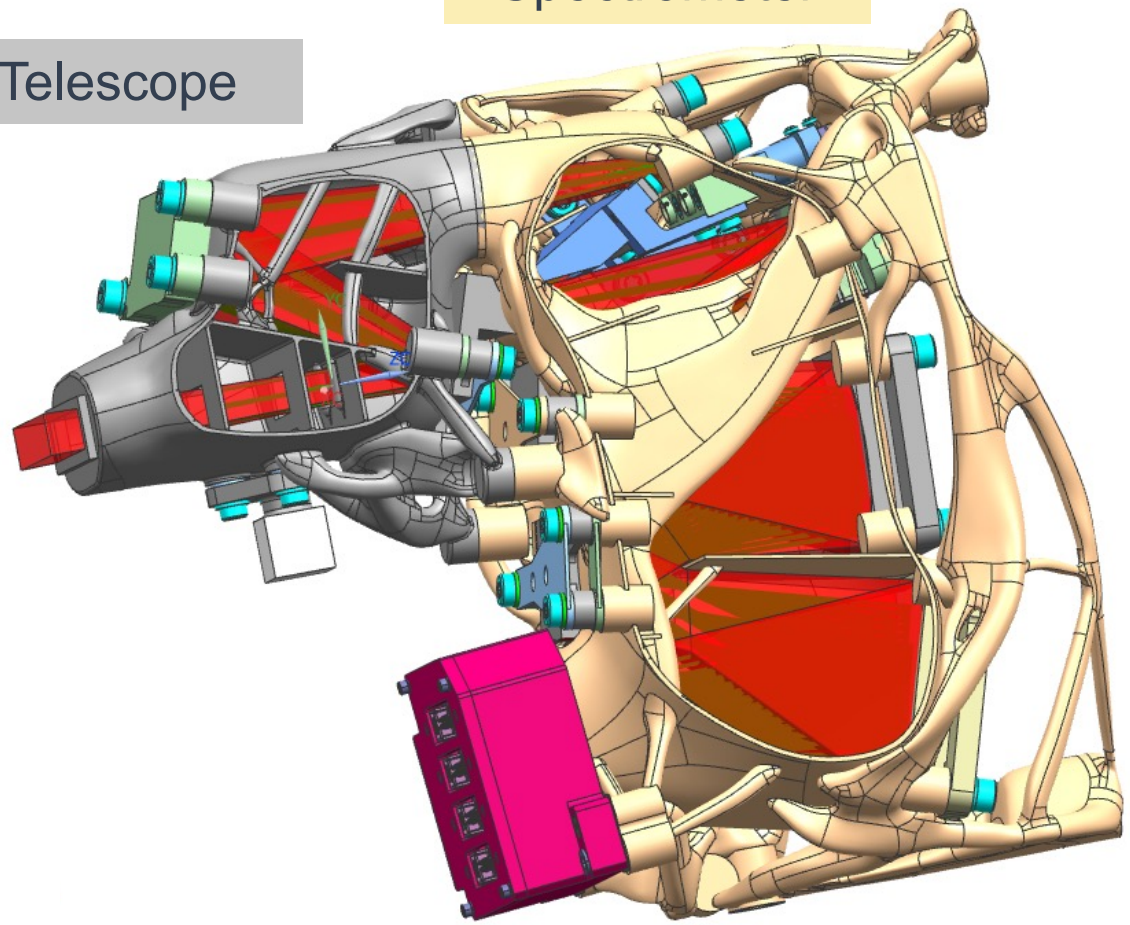
Optical design

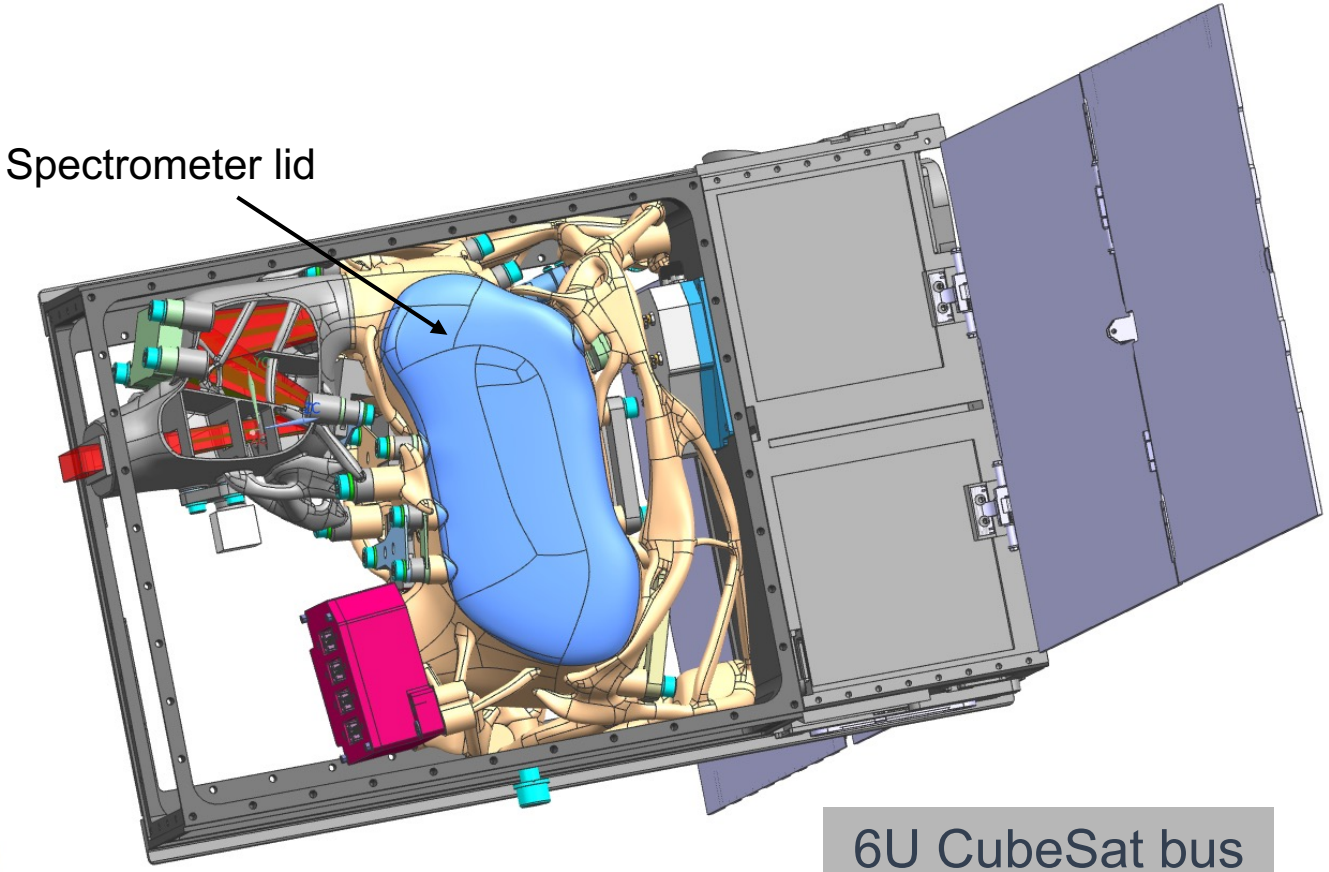


Also spectral and radiometric calibration (not shown)

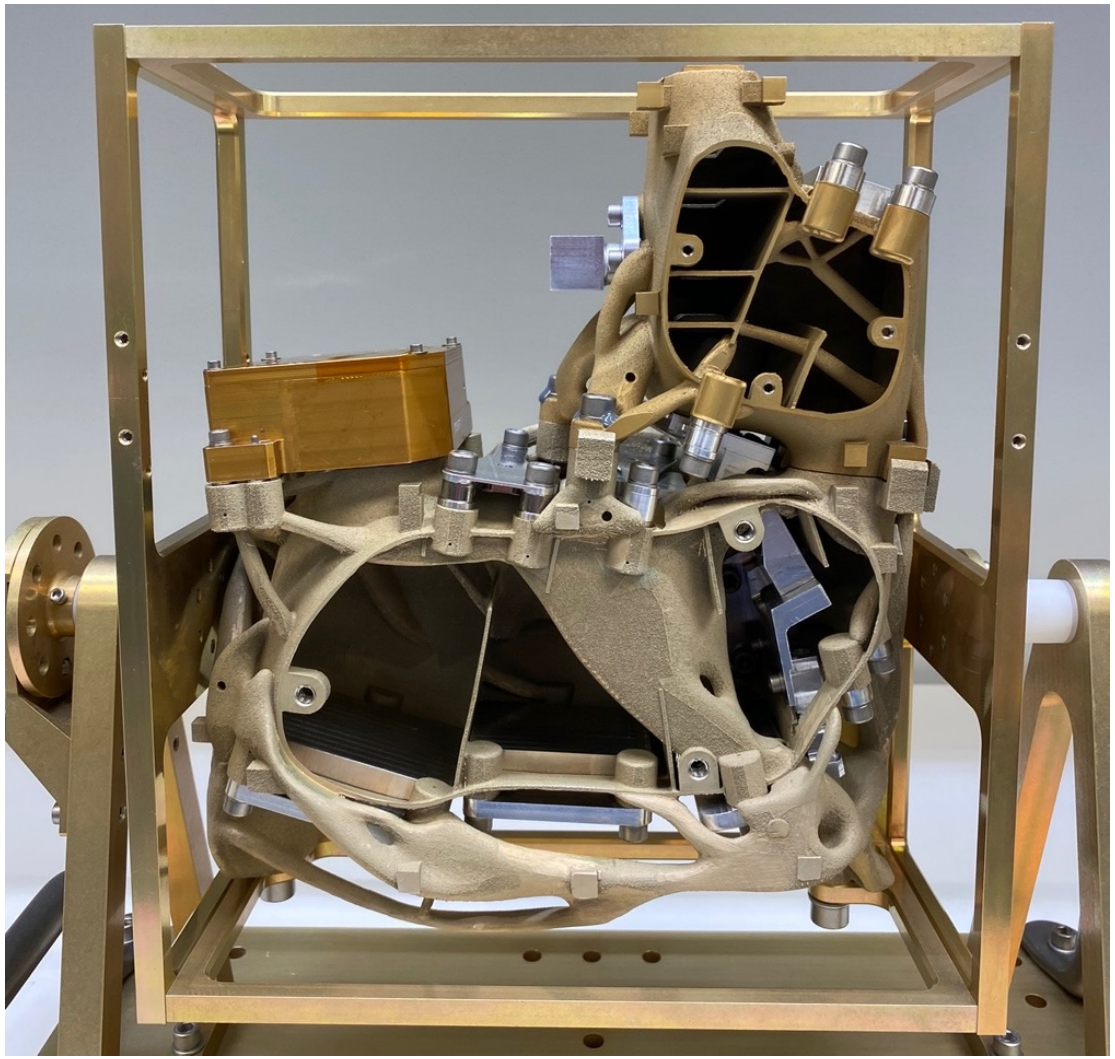
TNO innovation for life

Instrument design

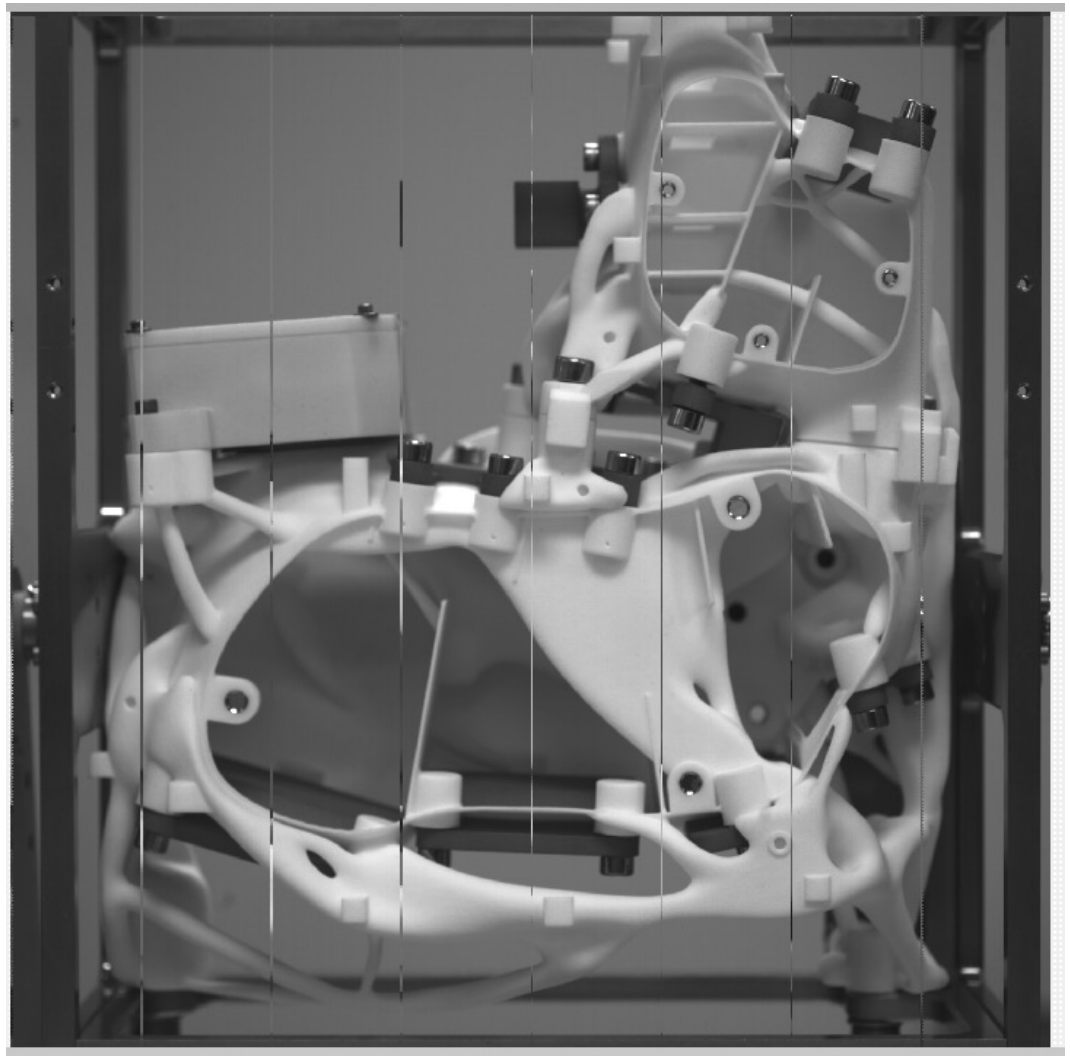




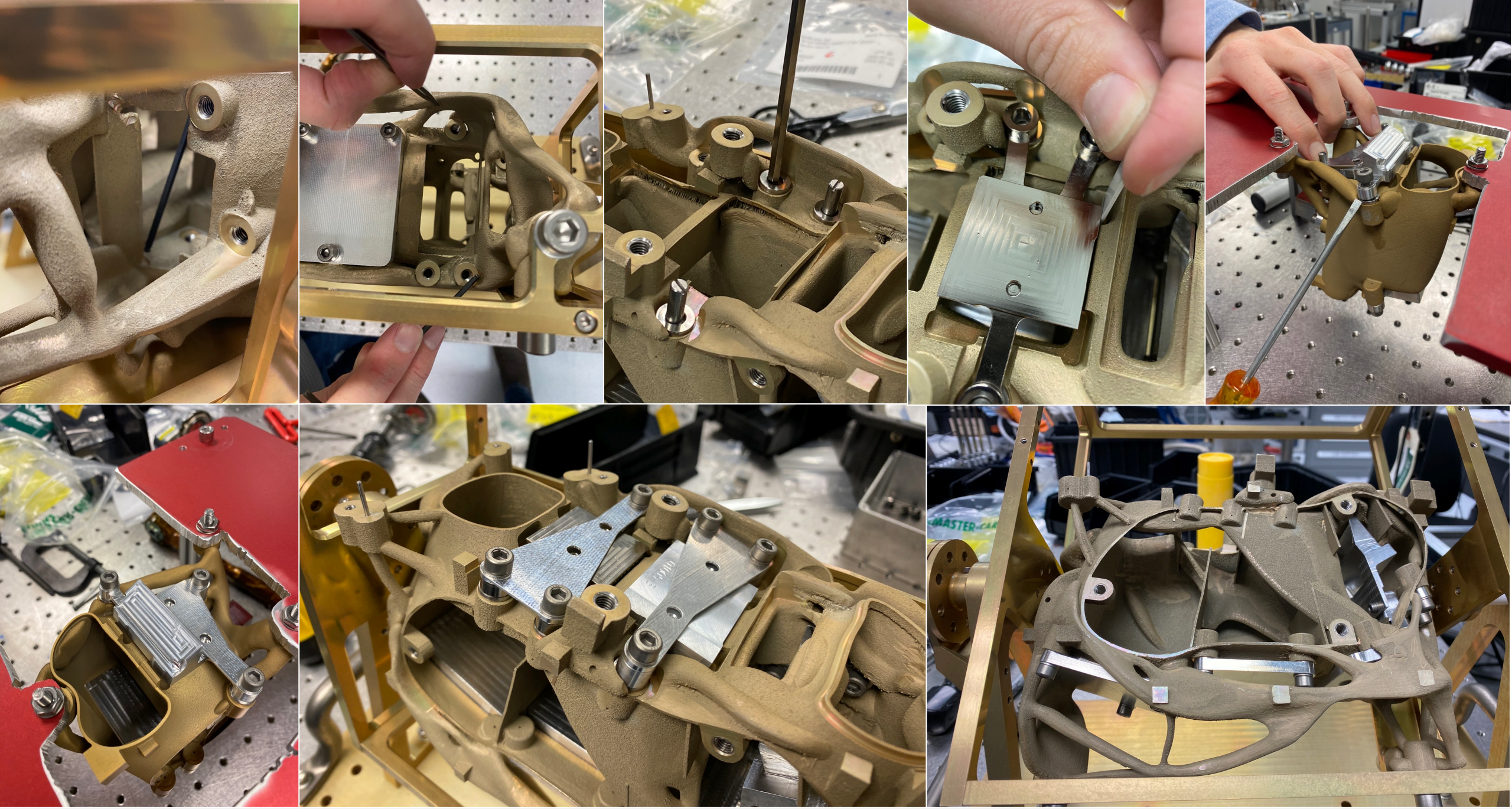
Breadboard testing successful



CHAPS-D breadboard



CHAPS-D selfie (of plastic model)

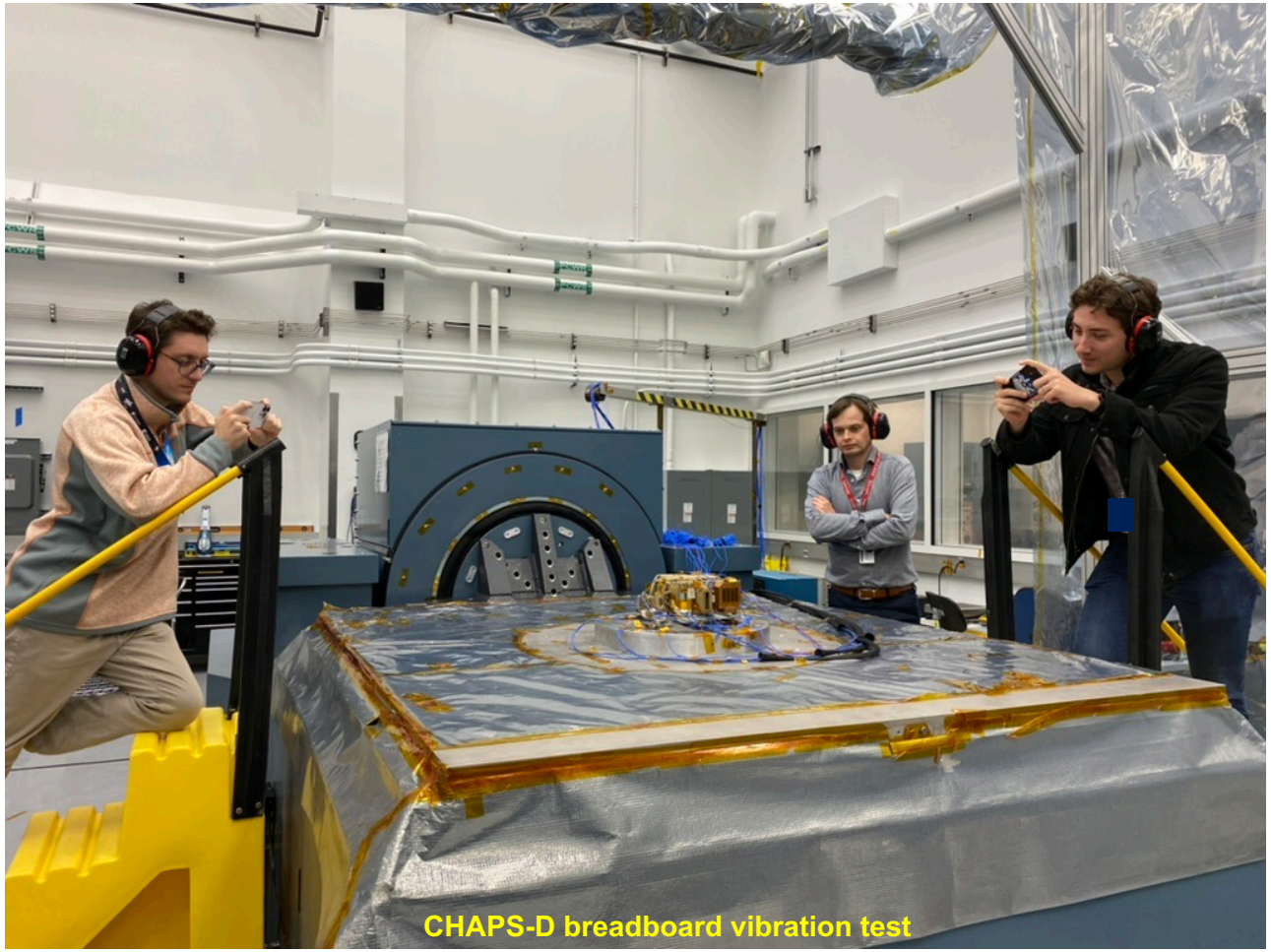


Proposition: Miniaturization leads to different/greater science potential than current, large satellites

- Less expensive (helpful)
  - Can be deployed on small satellite or hosted payload
  - Can duplicate current Aura/OMI data products in polluted areas at a substantially lower cost, greater ease of use, and/or with a lower deployment risk posture
- Enables complementary measurements (good)
  - Can augment large, traditional atmospheric composition survey missions (e.g., TROPOMI, TEMPO)
  - Higher spatial resolution can be a counterpart focused on pollution hot spots
  - Could complement another kind of measurement (like MAIA's aerosols) for "higher-level" understanding (e.g., public health impacts)
- Enables constellation measurements (better)
  - Smaller and lower-cost means multipoint measurements feasible (free-flier or hosted payload)
  - Could achieve scientific goals of high spatial *and* temporal resolution with greater flexibility and faster development timeline
  - Heterogenous constellation of CHAPS instruments, each with optical characteristics (e.g., wavelength range/resolution, spatial resolution, field of view, SNR) and an orbit tuned for particular species of interest, including NO_2, SO_2, O_3, CH_2O, methane, CO, aerosols, clouds, or combinations thereof (considering CHAPS instruments making measurements over wavelength ranges between 270 and 2400 nm)
- Enables new science (best)

Current status

- CHAPS-D currently in design phase
  - Optical design complete
  - Preliminary mechanical, electronics design complete
  - Breadboard environmental testing complete
  - CDR(s) spring/summer 2023
- Airborne flight instrument fabrication/calibration 2023
- Ground-based, airborne demonstrations 2023/4 [TRL 5]


CHAPS-D breadboard vibration test

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