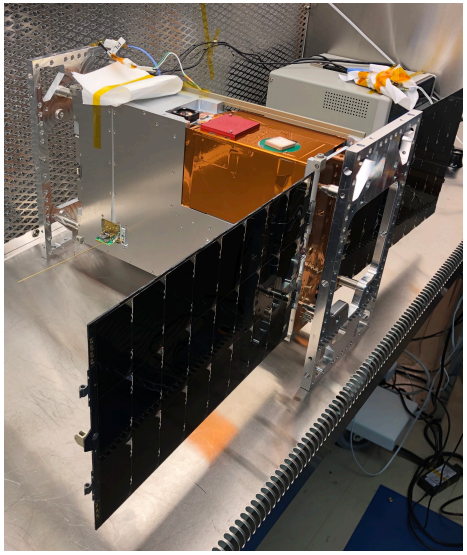

Operations Update for the Deformable Mirror (DeMi) CubeSat

Rachel Morgan[1]

Sophia K. Vlahakis[1], Gregory W. Allan[1], Ewan Douglas[2], Jennifer N. Gubner[1], Yeyuan Xin[1], Paula Do Vale Pereira[1], Bobby Holden[1], Christian A. Haughwout[1], Gabor Furesz[1], Mark Egan[1], John Merk[3], Joey Murphy[1], Kerri L. Cahoy[1]

1. Massachusetts Institute of Technology, 2. University of Arizona, 3. Aurora Flight Sciences

Bus provider: Blue Canyon Technologies

Sponsor: DARPA

Overview

- DeMi payload overview
- Optical Payload Alignment and Calibration
- Flight Integration and Environmental Testing
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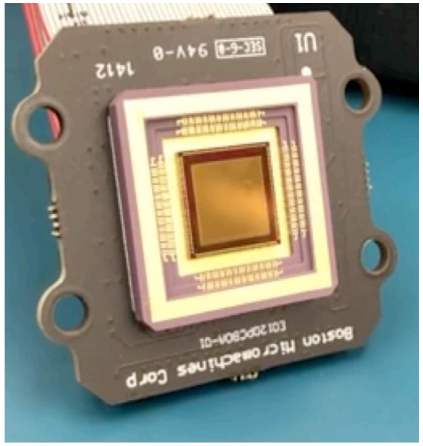
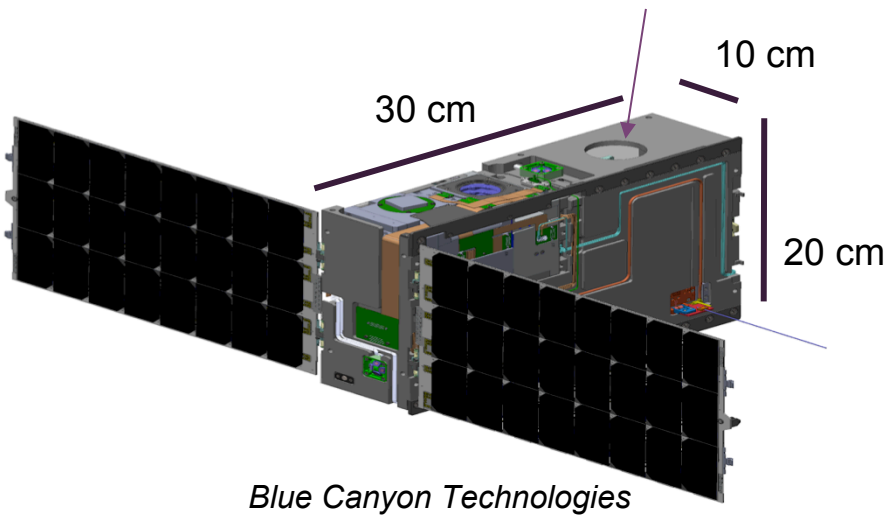
- Conclusions



140 actuator MEMS DM from Boston Micromachines Corporation

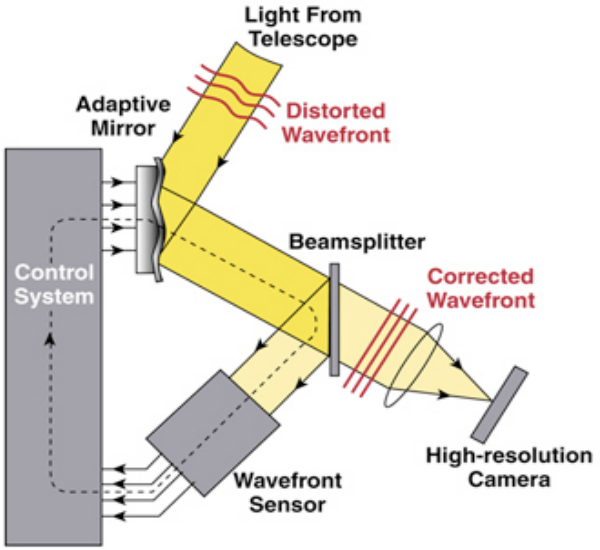
mini space telescope



Blue Canyon Technologies

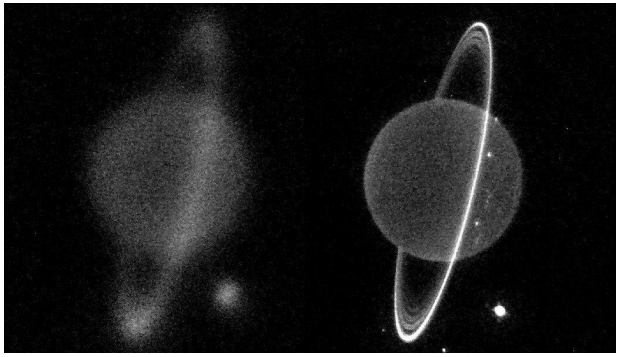
Motivation: Adaptive Optics in Space

- DeMi: Deformable Mirror Demonstration Mission
- Deformable mirrors correct aberrations and speckles due to mechanical, thermal, and optical effects as part of AO system
- Enables high wavefront stability required for exoplanet direct imaging with coronagraphs
- DeMi space technology demonstration mission will show MEMS DM performance in response to **launch vibrations**, **space radiation effects, orbital thermal environment, and long duration space operations**



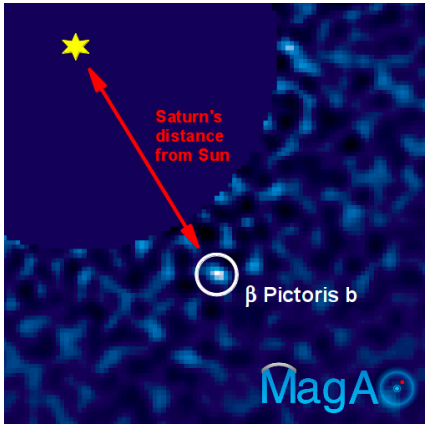
Claire Max, CfAO

Diagram of typical AO (adaptive optics) system



Hammel and Pater

Ground-based observations of Uranus before/after AO correction



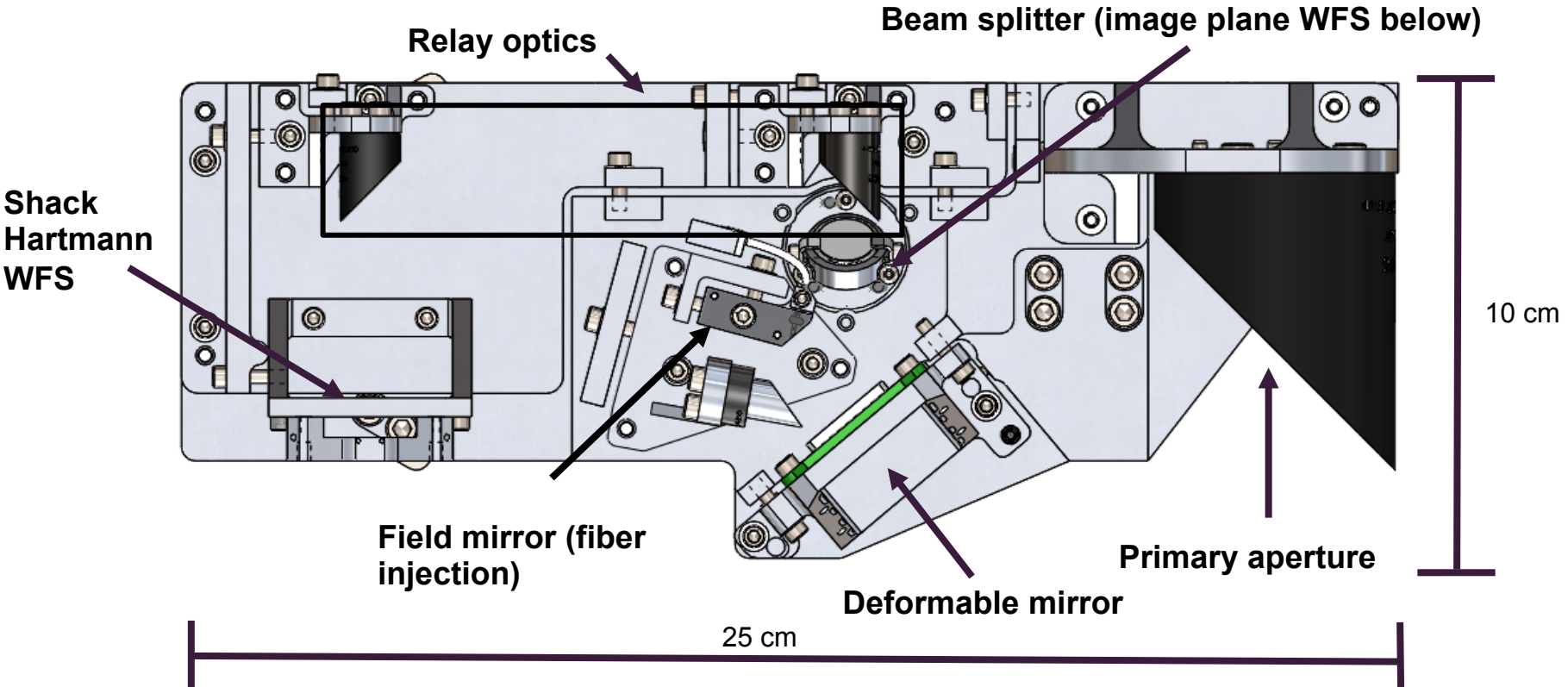
Jared Males, UA

Image of gas giant exoplanet Beta Pictoris B with Magellan Adaptive Optics instrument

DeMi Mission Overview

CubeSat mission objectives:

1. On-orbit characterization of 140-actuator BMC MEMS deformable mirror
2. On-orbit demonstration of closed-loop mirror control using both a Shack Hartmann and an image plane wavefront sensor
3. Improve the point spread function (PSF) of an astronomical source



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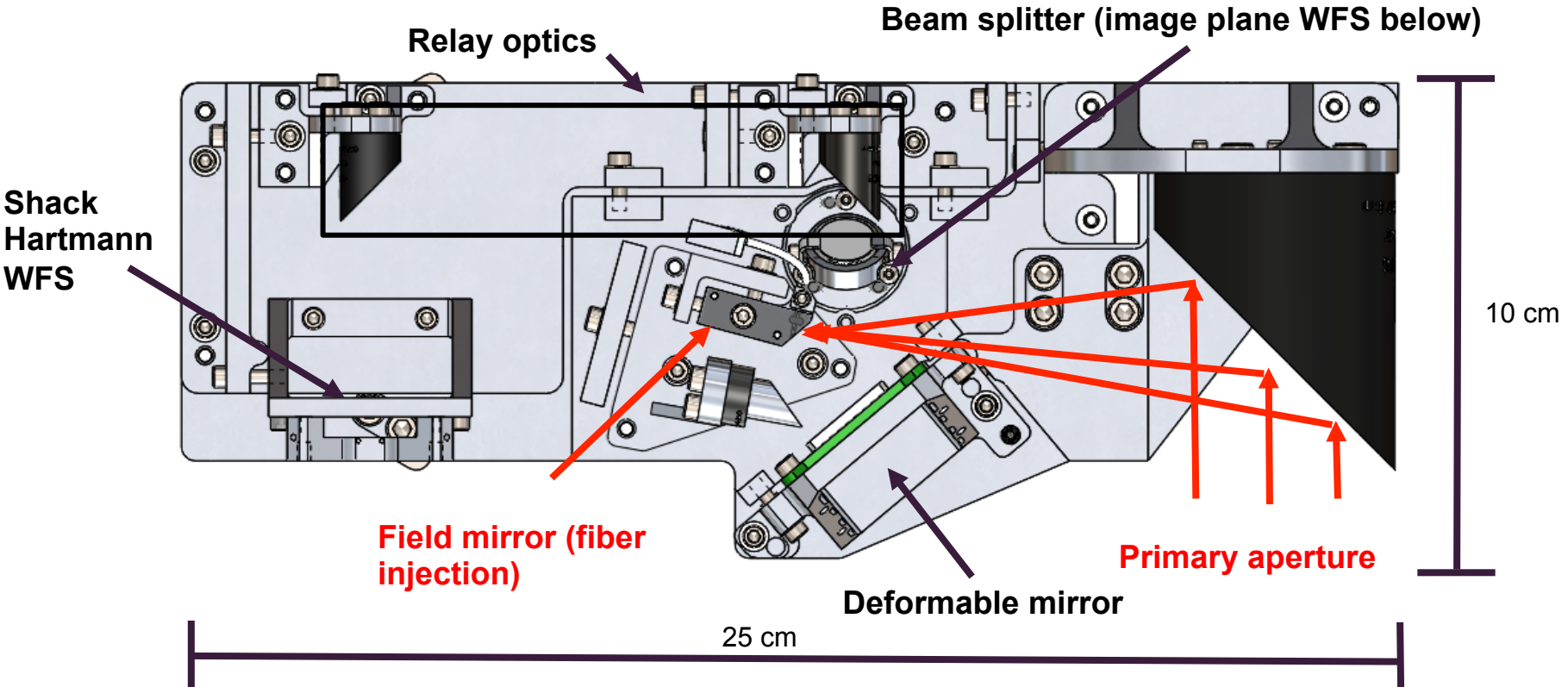

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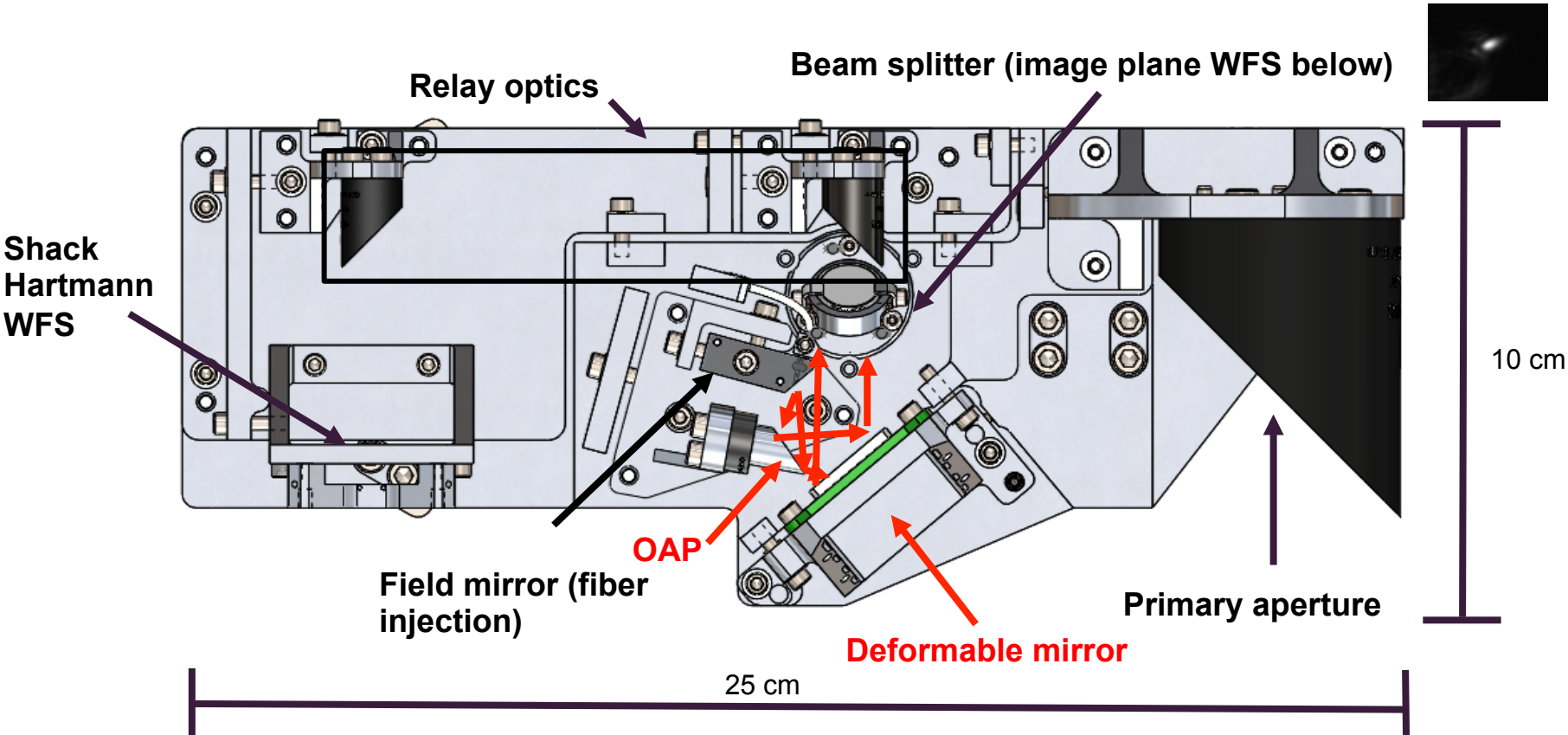

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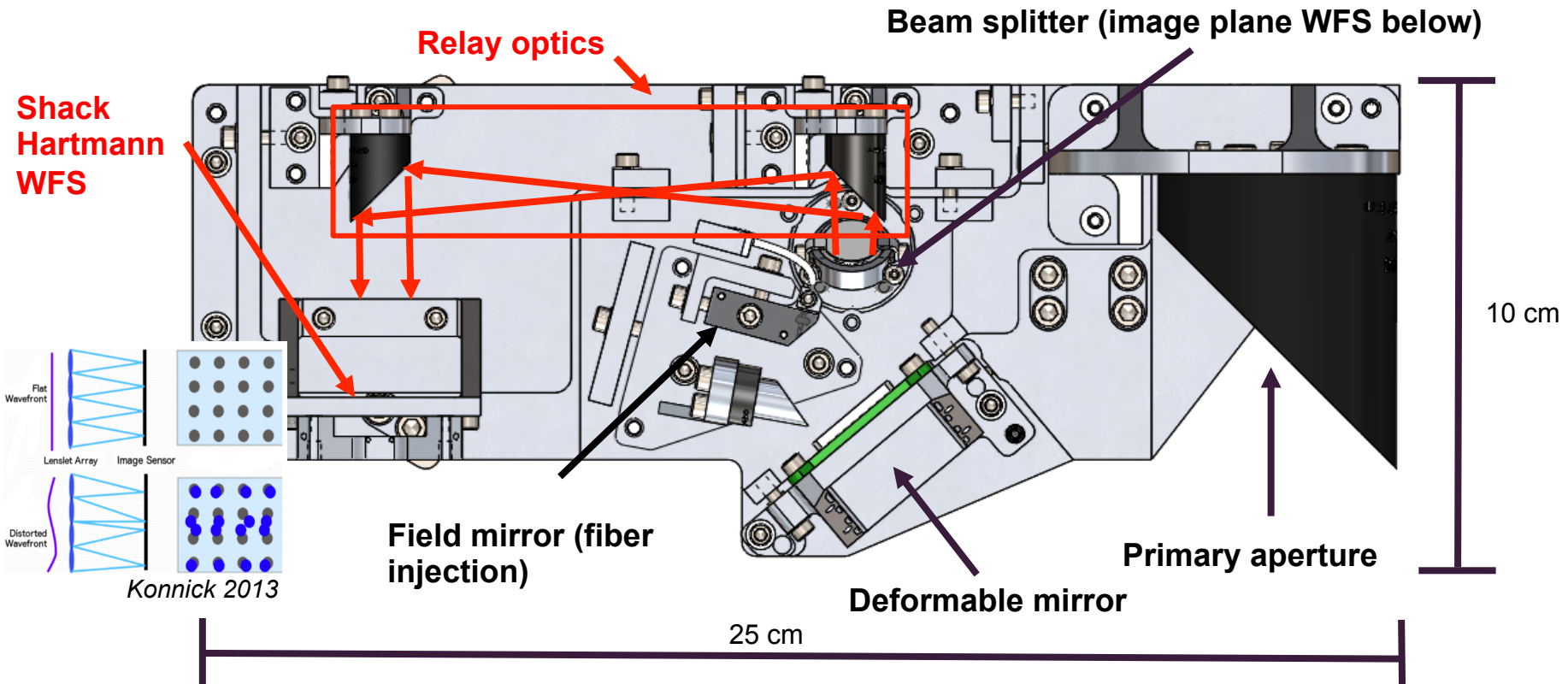

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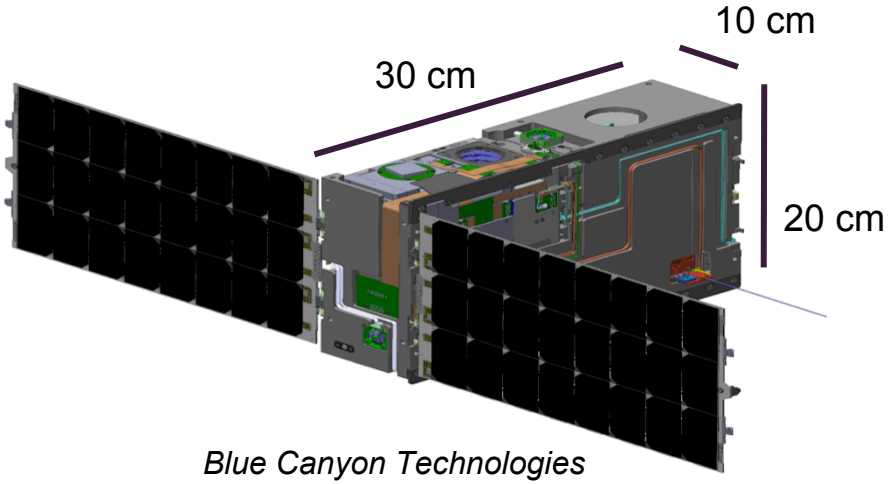
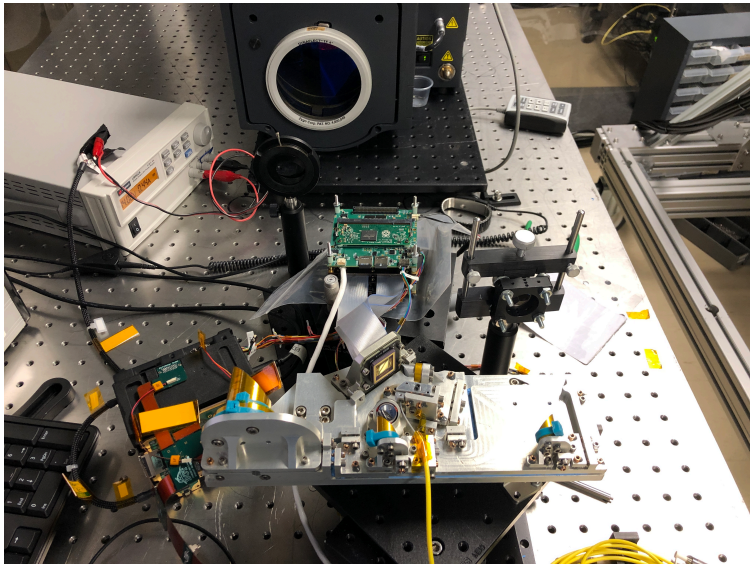
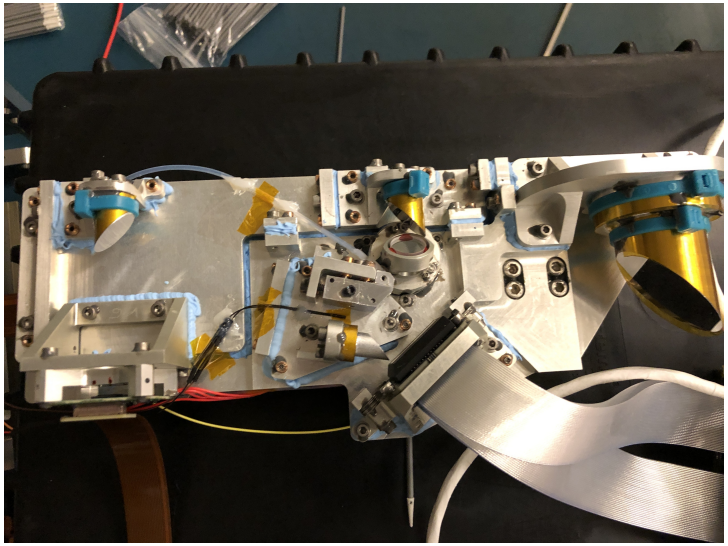
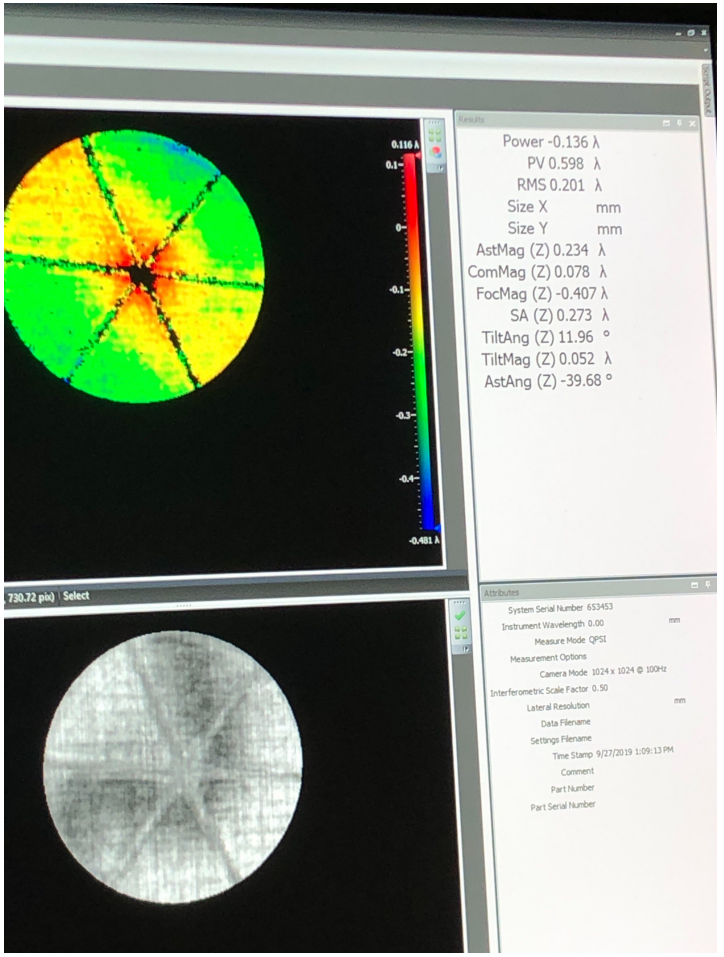


Blue Canyon Technologies

Flight Alignment



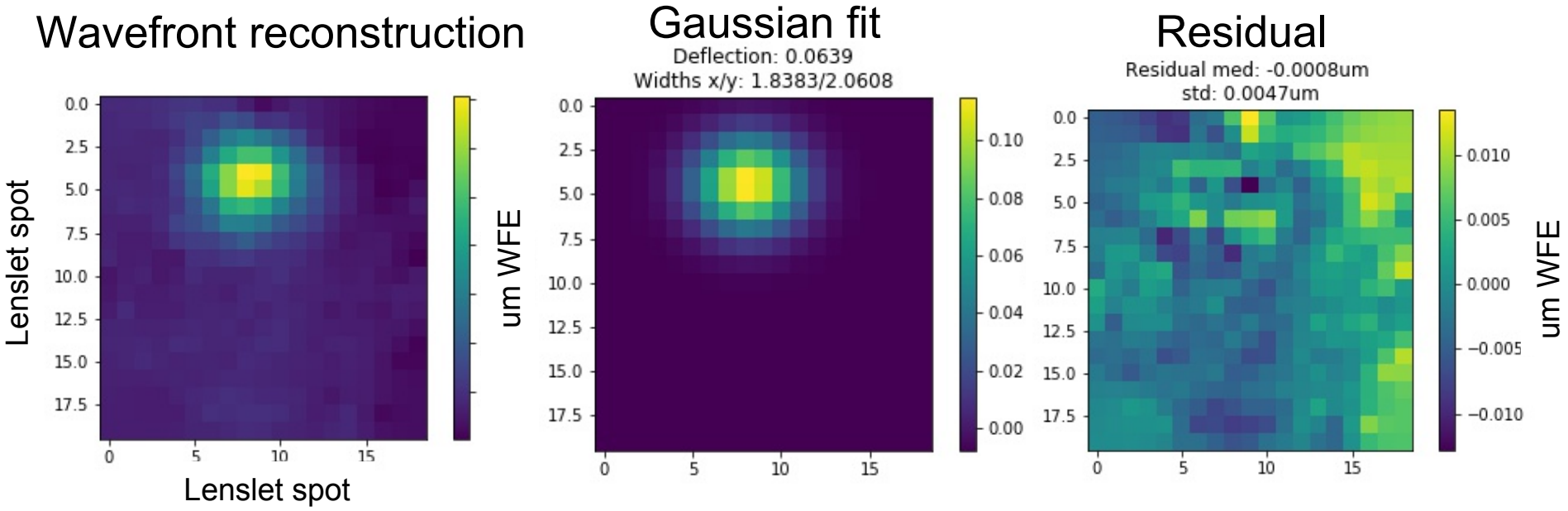




Aligned to requirement of <0.25λ wavefront error RMS (or less than 158 nm WFE RMS)

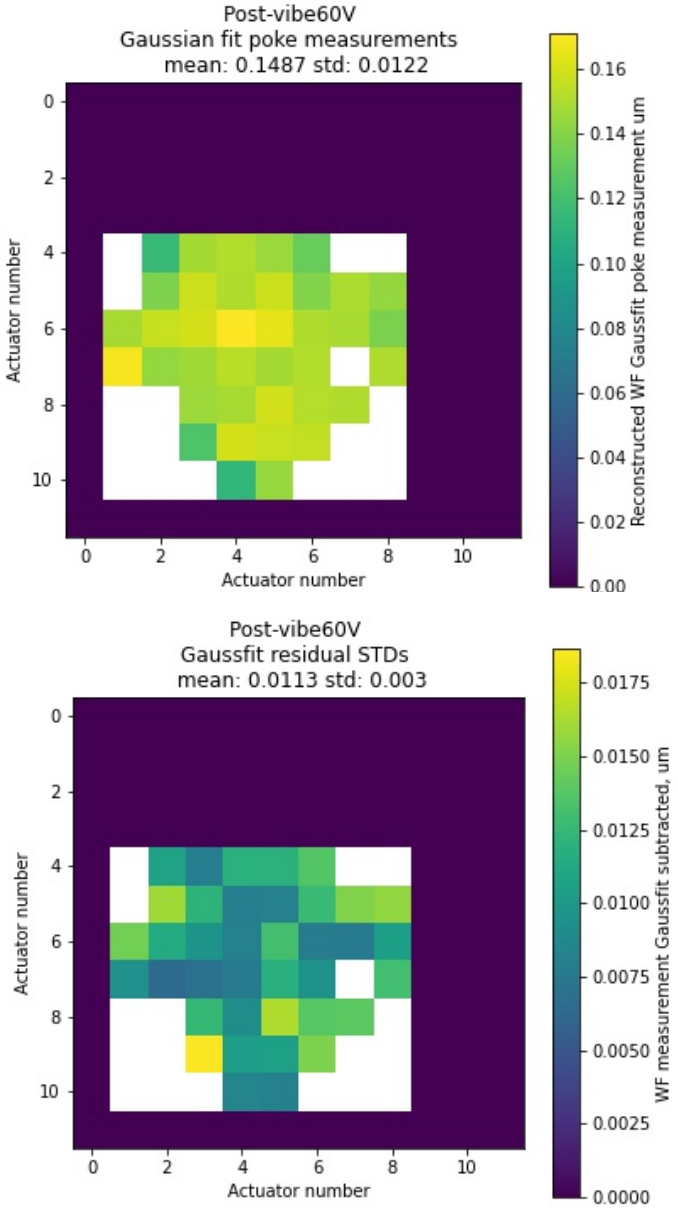
SHWFS actuator measurements

- Process SHWFS measurements with zonal reconstruction
  - As = Dw
- Using Gaussian fit to wavefront reconstruction to measure actuator deflection:
  - Amplitude → deflection measurement
  - Standard deviation of residual → measurement uncertainty



Flight payload calibration analysis

- Comparing payload data to calibration interferometer measurements:
  - 90% calibration factor to account for angle of DM in payload based on POPPY model:
    - 0.17 um 60V Zygo measurement -> 0.15 um payload measurement
  - Payload SHWFS data agrees with Zygo measurements to within measurement uncertainty (~15 nm for 60V measurements)
  - Actuator measurements towards edges of visible laser field are less accurate (dimmer SHWFS spots, less accurate WF reconstruction) and are filtered out for this analysis



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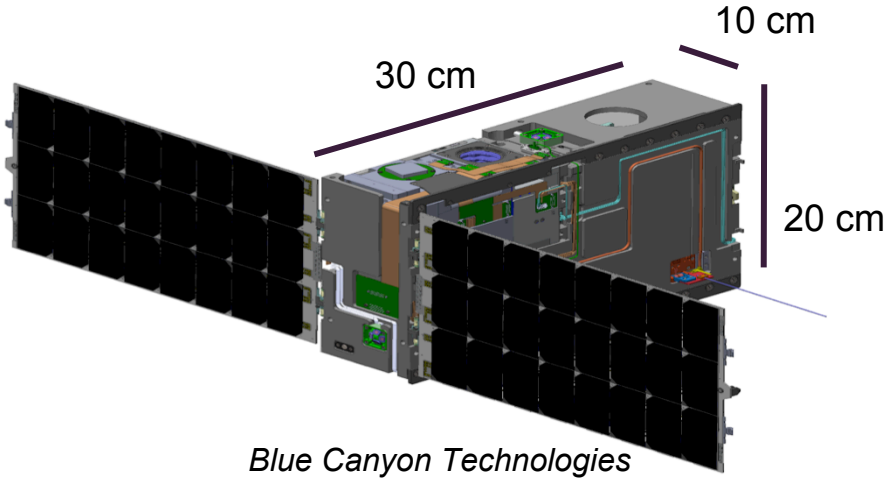
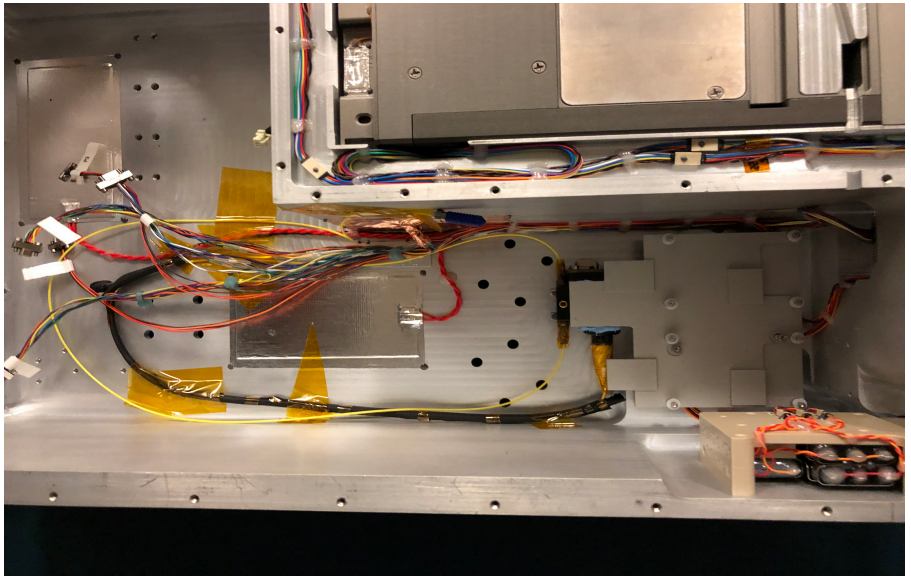
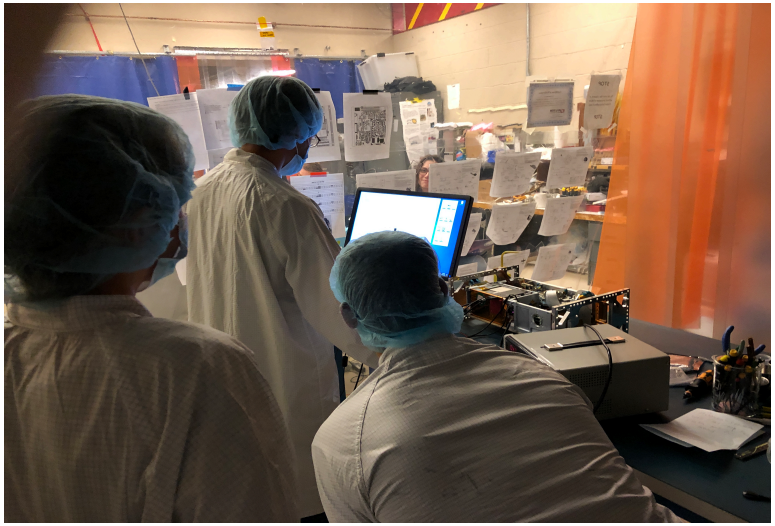
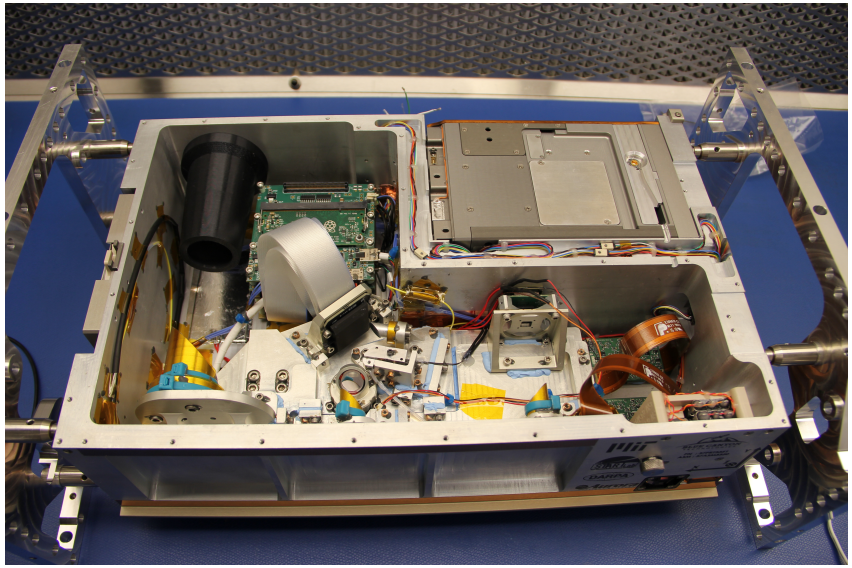


Blue Canyon Technologies

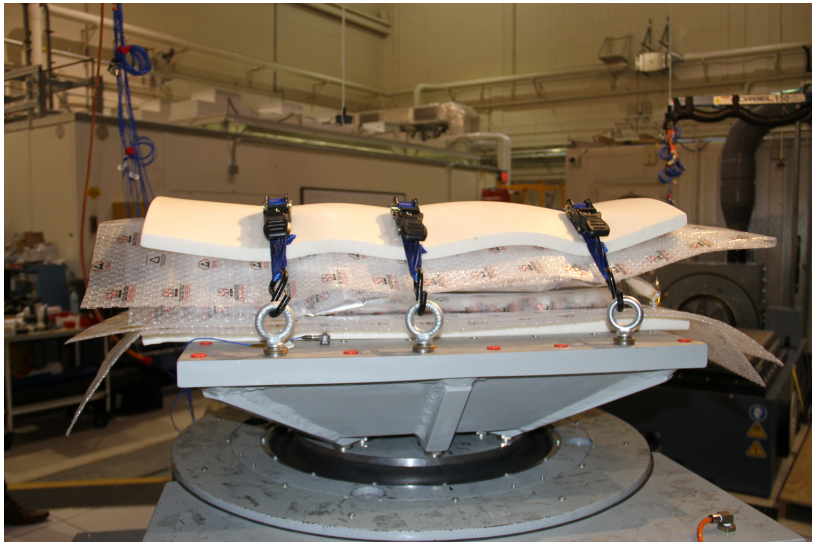
Flight Integration







Environmental Testing



- Environmental testing performed at MIT Lincoln Lab
- Thermal cycling -> TVAC -> vibe
- Collected payload data at each test phase where it was safe to operate payload:
  - Camera calibration data
  - image plane PSF data
  - SHWFS poke test data

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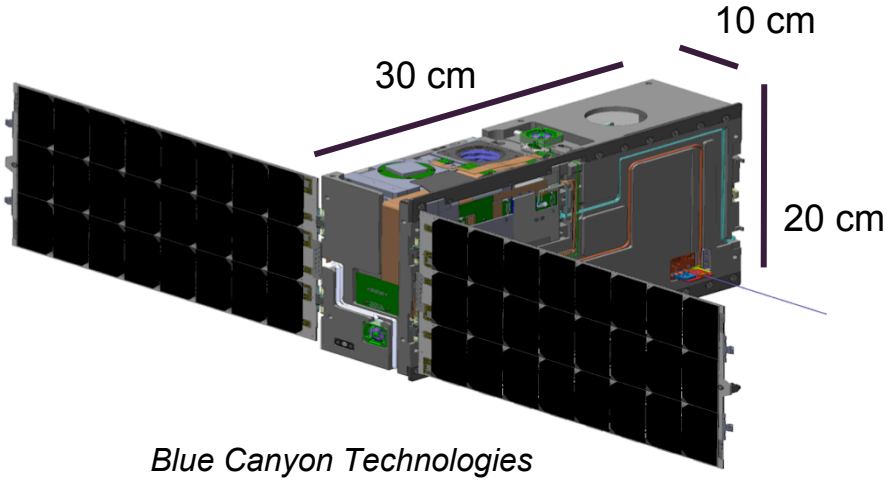
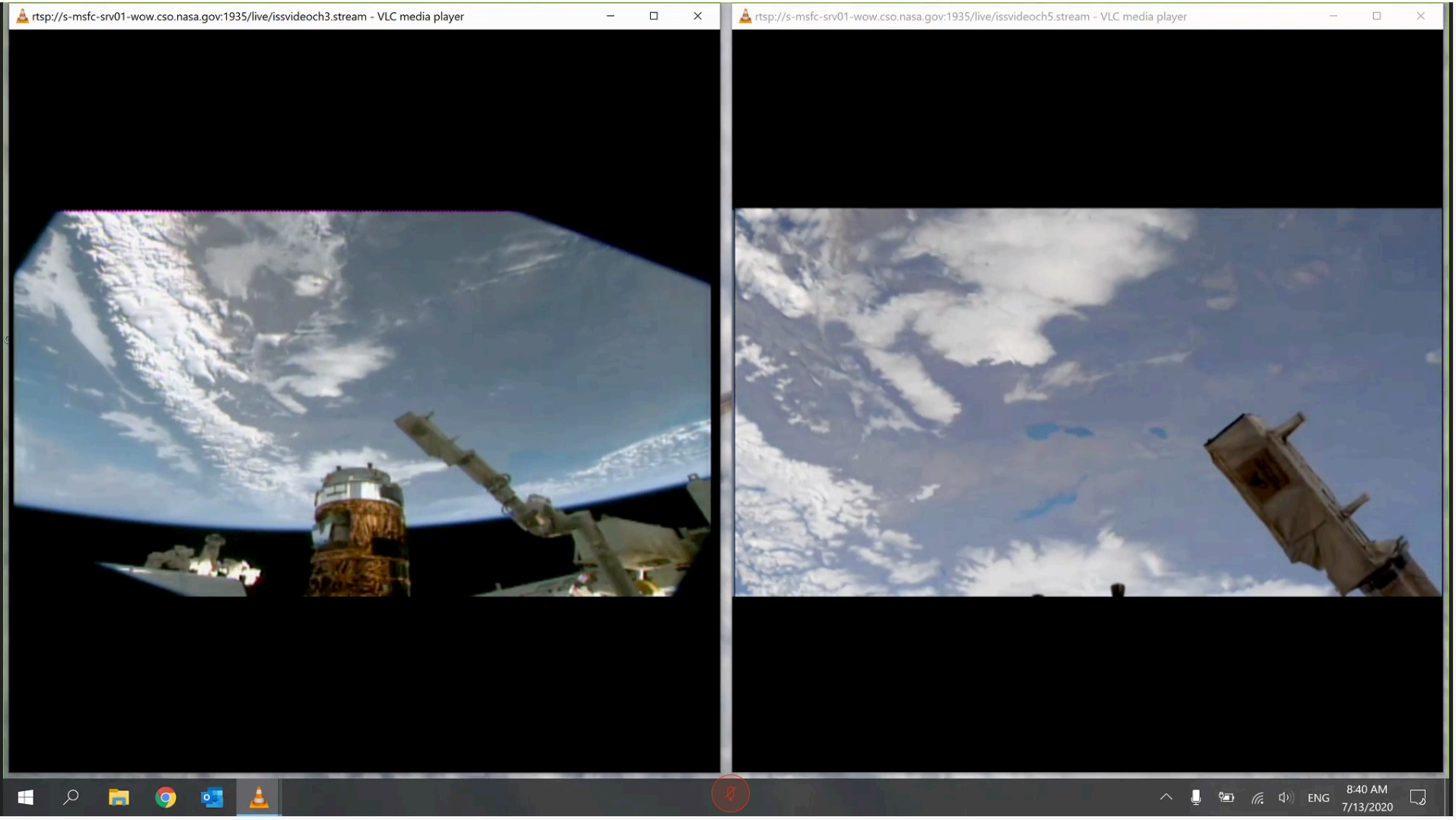


Blue Canyon Technologies

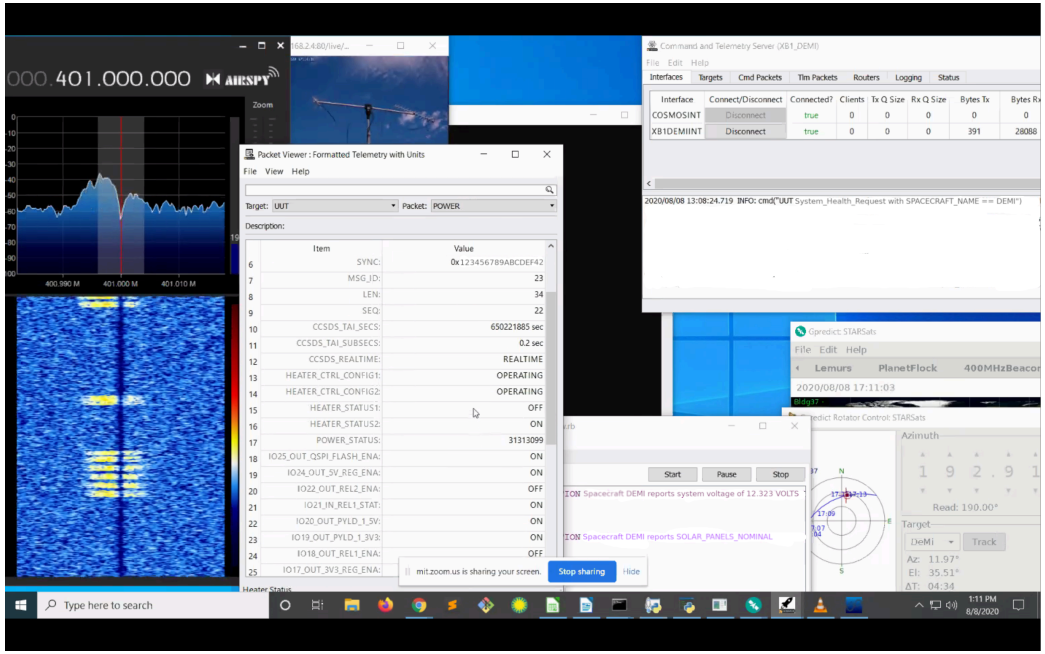
Launch Feb 15 2020 from WFF

Deployment from the ISS July 13



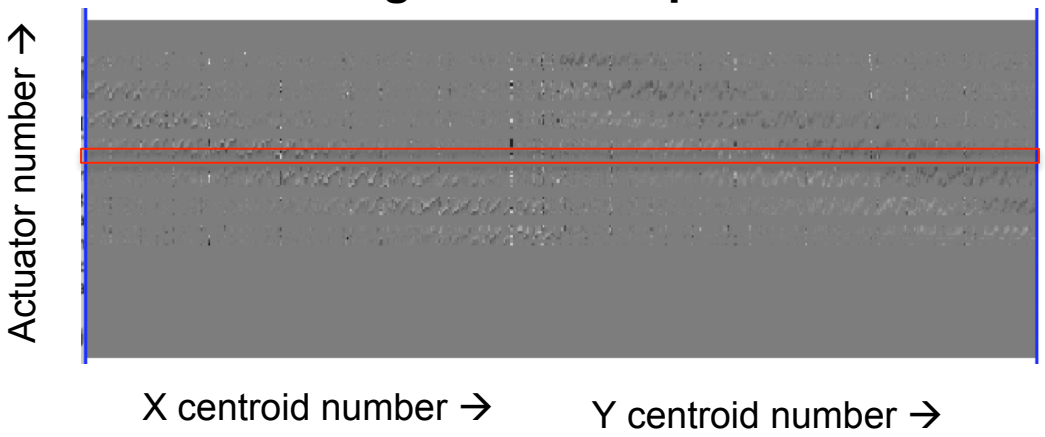
Operations Details

- 2 radios onboard: Lithium and Cadet
- Li is for day-to-day commanding, ground station at MIT
- Cadet for high rate downlinks, ground station at NASA Wallops Flight Facility
- BCT uses open source COSMOS codebase from Ball Aerospace as basis for their ground operations software
- First contact 7/20/2020, >950 successful passes since then!



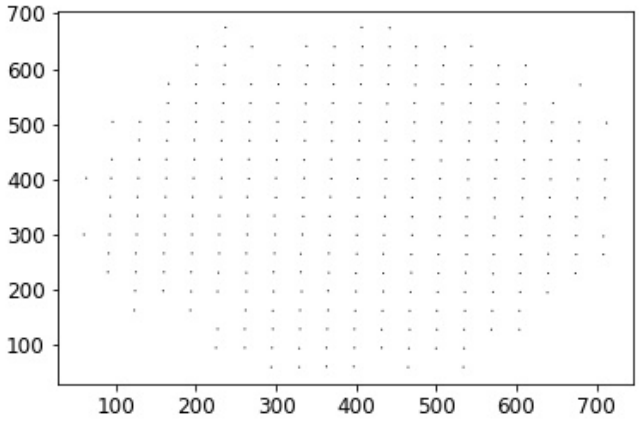
Actuator measurement data

Centroid displacement measurements for single actuator pokes:

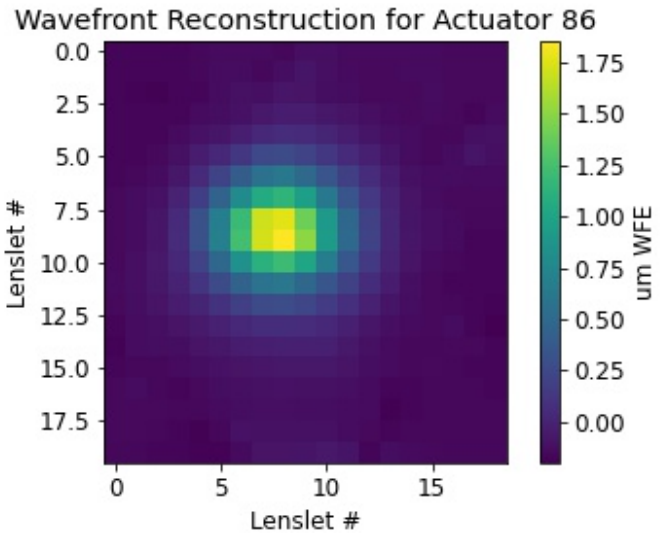


Each row corresponds to a single actuator poke measurement

Centroid displacements

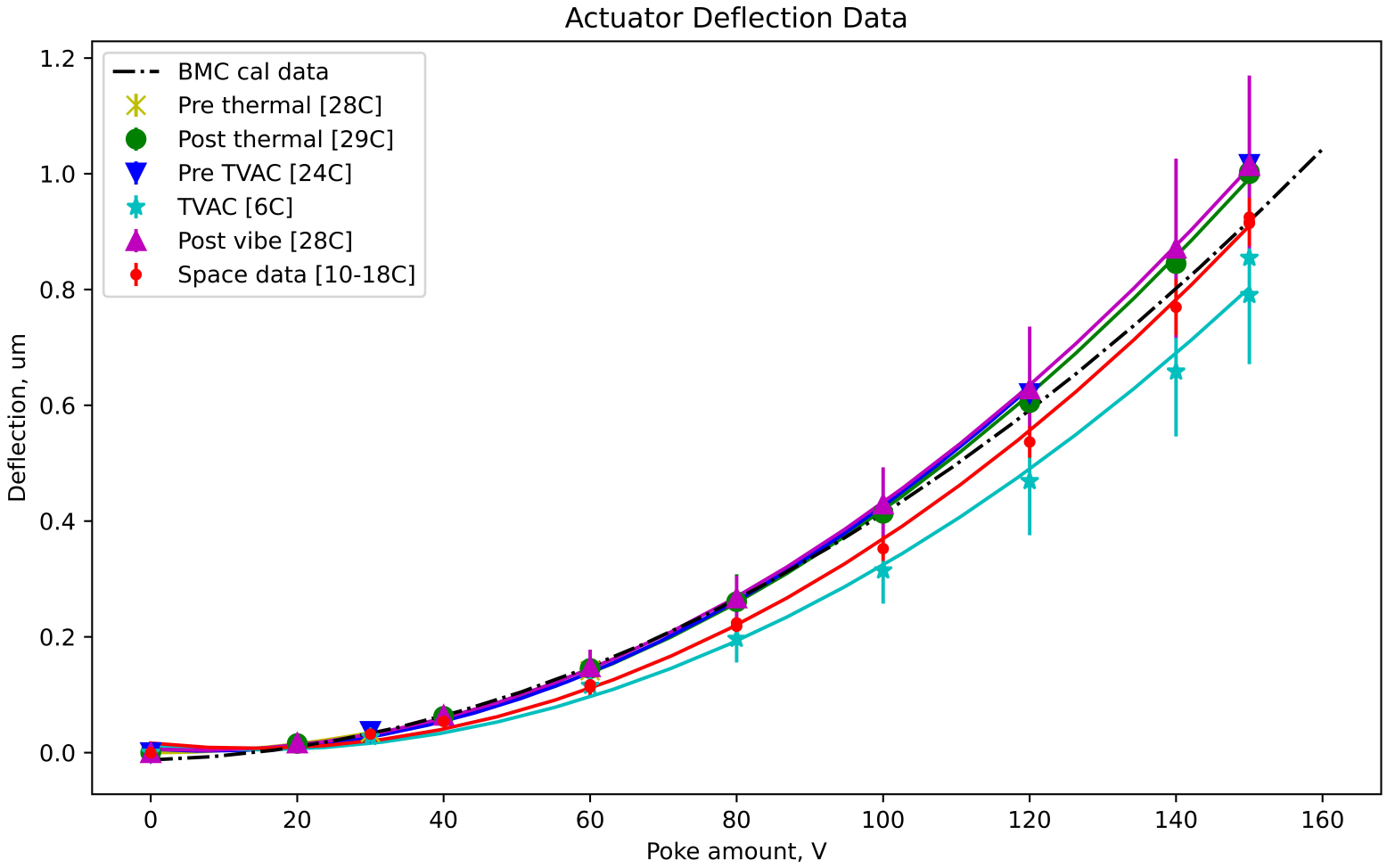


Zonal reconstruction for wavefront measurement



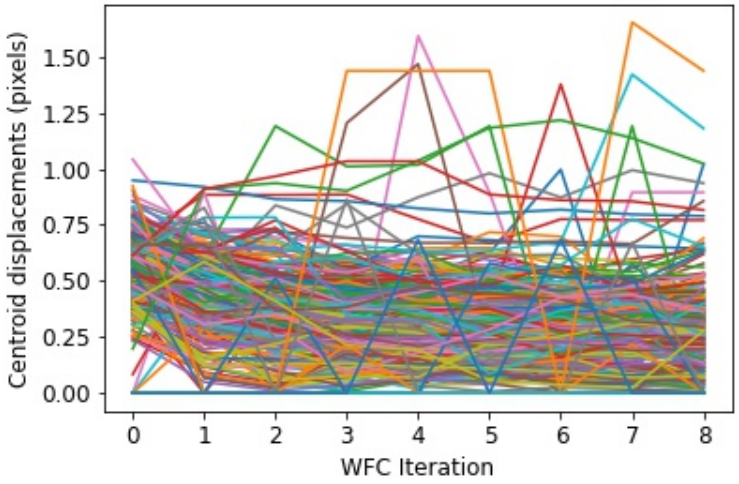
Actuator measurement summary

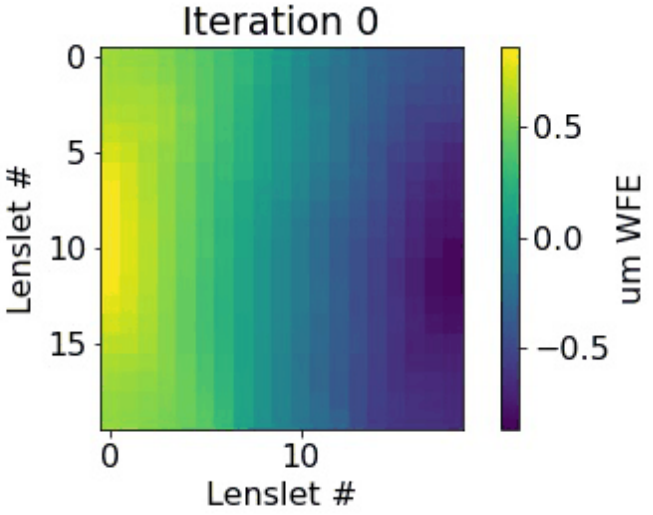
- Results agree well with ground testing data and calibration data from mirror manufacturer with same levels of measurement uncertainty
- Deflection appears dampened at low temperatures

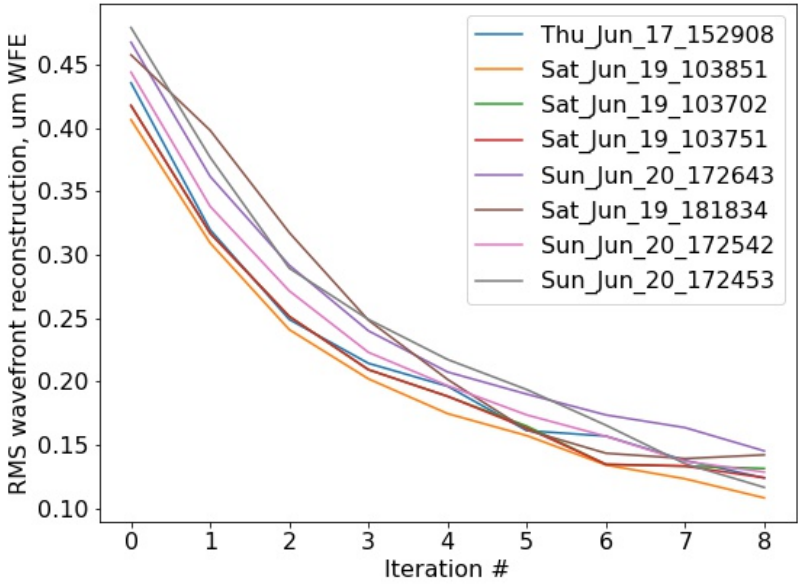


Wavefront control experiments

Centroid displacements at each iteration downlinked for analysis/wavefront reconstruction:





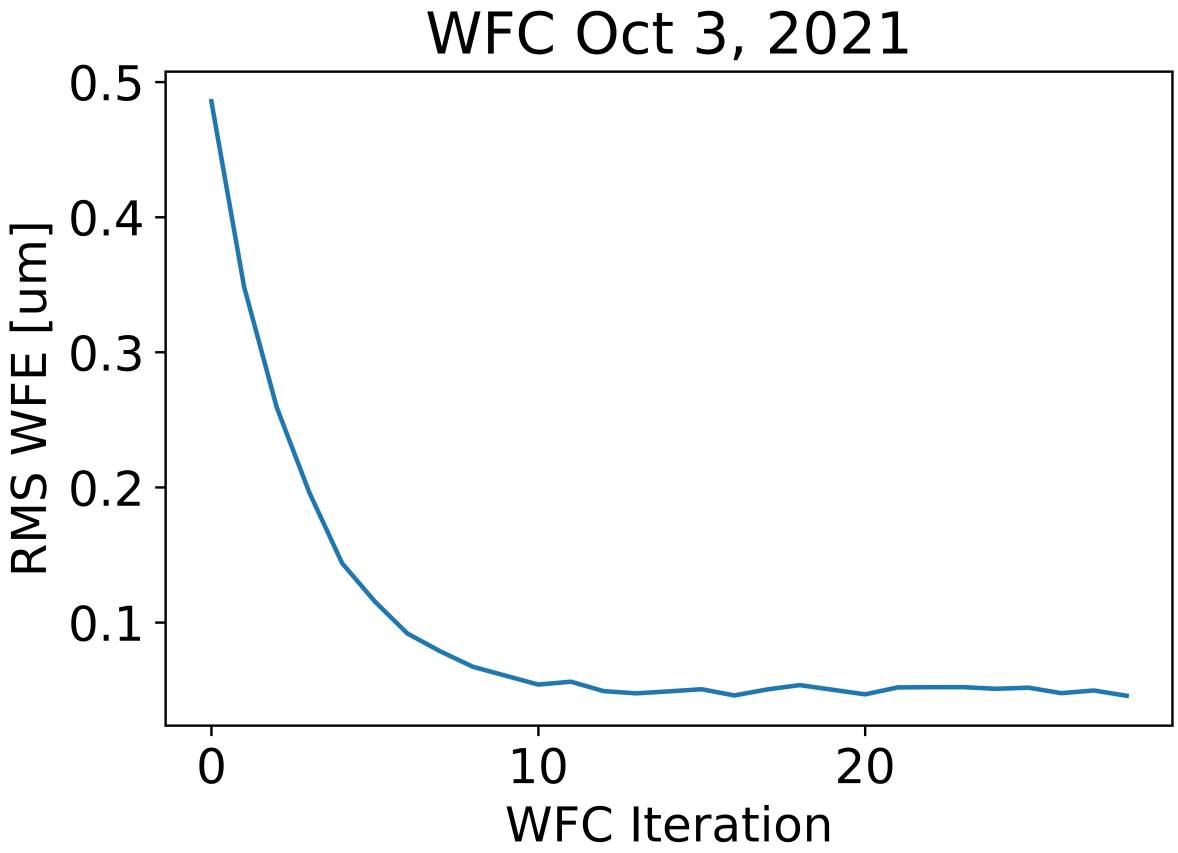


Summary of data from 8 WFC experiments in June 2021:

- RMS wavefront error reduced over 9 iterations from ~450 nm to <150 nm
- Close to payload requirement of correcting wavefront errors to <100 nm, plan to run experiments with more iterations in future

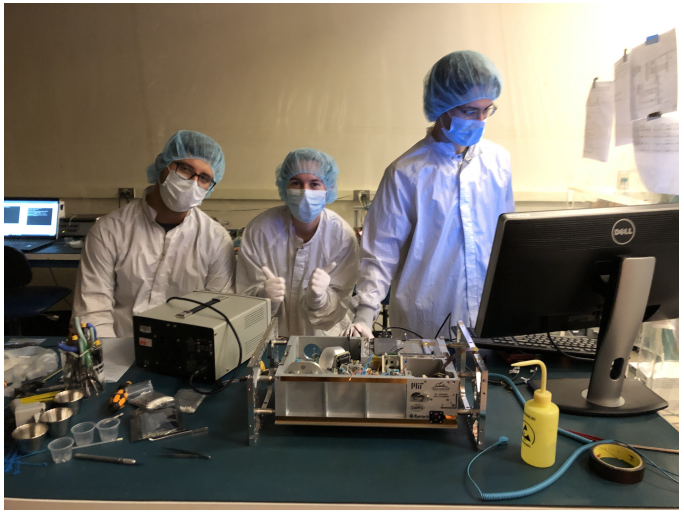
WFC Experiment

- Ran more WFC experiments, met the 100 nm requirement!



Conclusions

- DeMi was launched to the International Space Station Feb 15, 2020. Deployment happened in July 2020 and we have had >950 successful communications passes with the satellite!
- CubeSat payloads are an excellent platform to test new technologies in space, DeMi is gathering valuable data on MEMS DMs for future high-contrast imaging space telescopes
- *See recent publications for more info:* Morgan et al JATIS 2021 , Douglas et al Frontiers 2021



DeMi is sponsored by DARPA and managed by Aurora Flight Sciences (a Boeing Company)