MEMS DM developments in HCIT

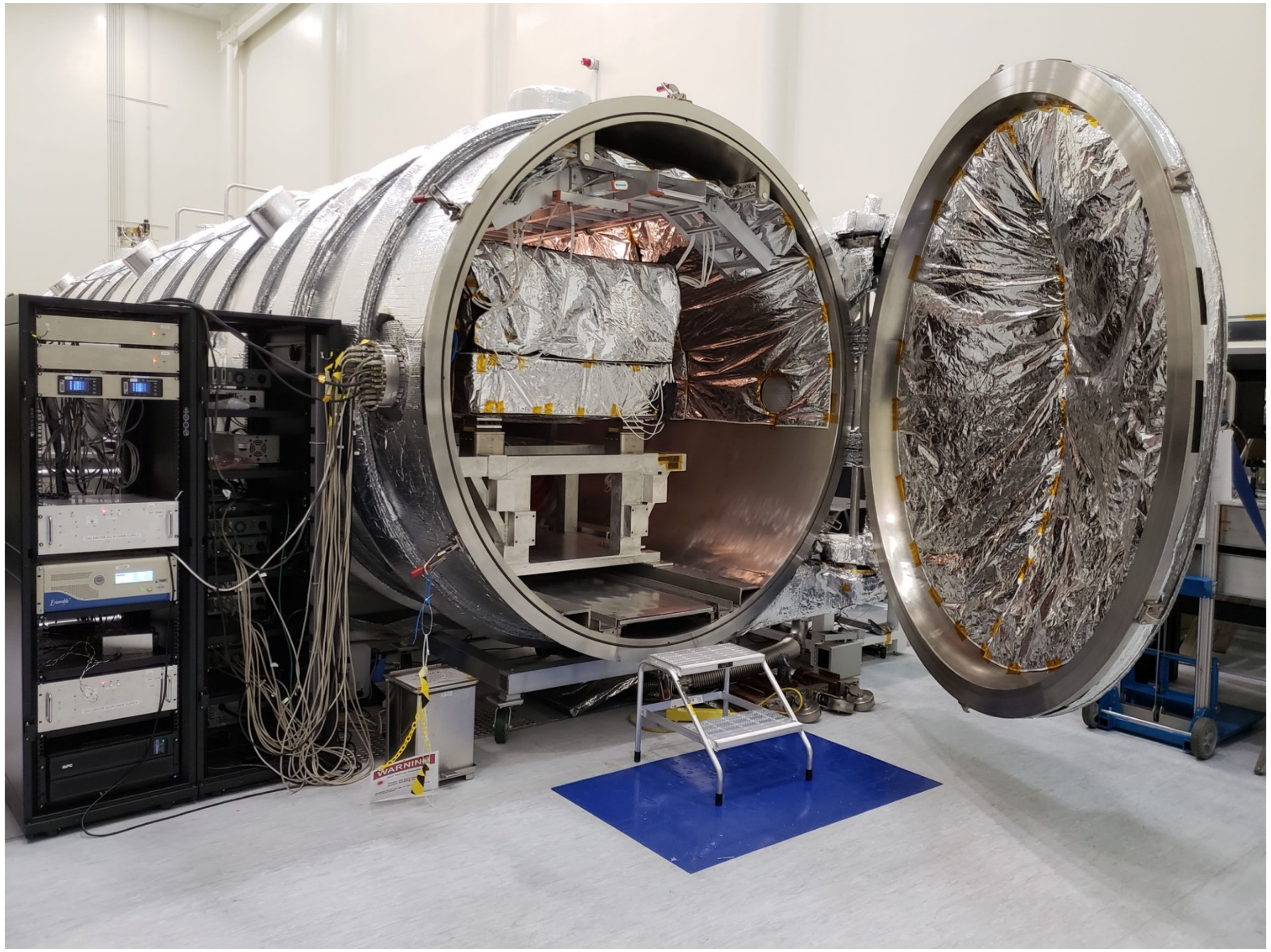
G. Ruane, E. Bendek, C. Mejia Prada, P. Poon, B. Peters, D. Liu, and others

Jet Propulsion Laboratory, California Institute of Technology

Jet Propulsion Laboratory
California Institute of Technology

MEMS DM development program in HCIT

- The ExEP-funded HCIT team at JPL is developing and testing MEMS DM technologies for future space-based exoplanet imaging missions.
- The hardware requirements are based on the goal of imaging temperate, Earth-sized planets orbiting F,G,K stars in reflected light.
- The scope:
    - Testing 1K and 2K DMs from Boston Micromachines (BMC).
    - Developing DM electronics (controller, cabling, connectors, …).
    - Environmental testing.
    - Paving the way for a flight-ready wavefront control system.



High contrast imaging testbed (HCIT) facility
Jet Propulsion Laboratory (JPL), Pasadena, CA

A (partial) census of the MEMS DMs in HCIT

	BMC 1K actuator (34×34) DMs	BMC 2K actuator (50×50) DMs
Tested	x029 - SG (tested on GPCT -> PIAACMC) x015 - SG (environmental testing -> GPCT)	50.A - EG (DM2 on DST, 65 V electronics) 50.B - EG (DM1 on DST, 65 V electronics)
Not tested	x035 - SG (environmental testing) … and more.	50.C - EG (environmental testing) 50.D* - SG (planned DST DM1; 100 V) 50.E* - SG (planned DST DM2; 100 V) 50.F* - SG (environmental testing) 50.G - EG (environmental testing)

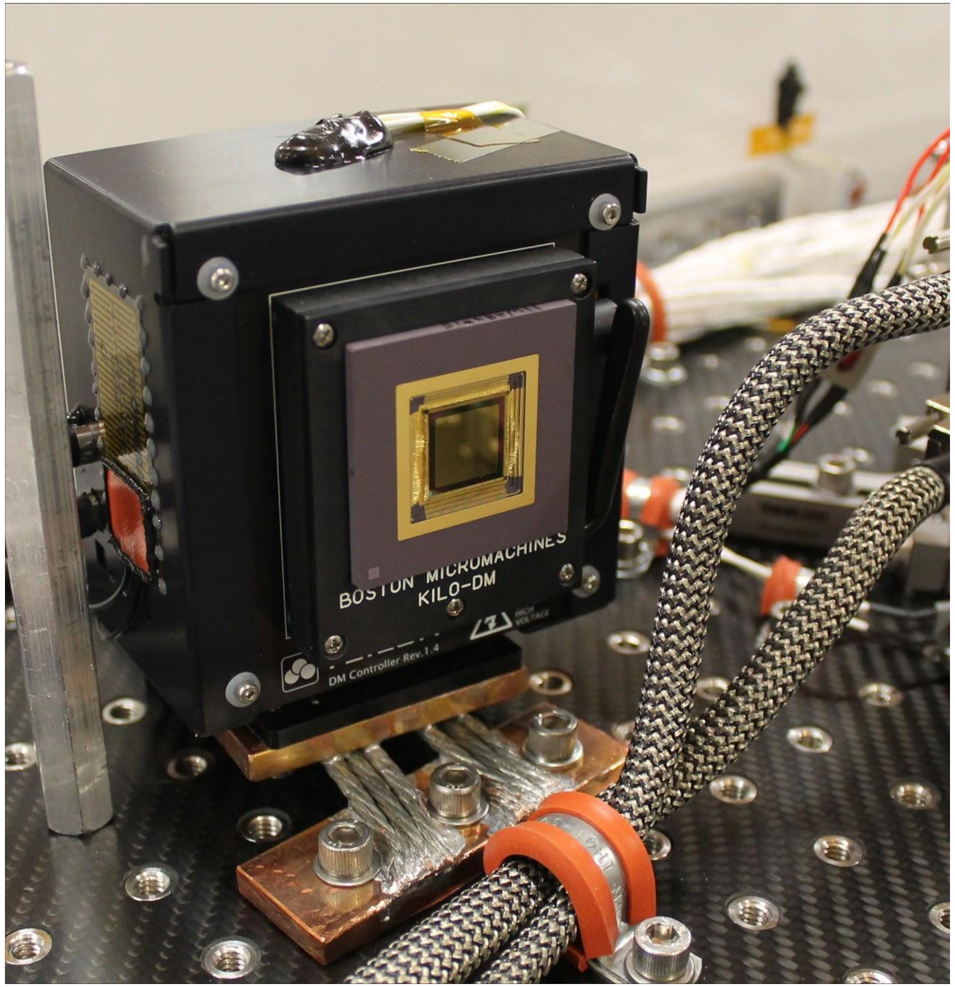
Legend

- (green) Tested on coronagraph testbed.
- (orange) Not tested on coronagraph testbed.

*Coronagraph testing planned.
EG: Engineering grade (>a few anomalies)
SG: Science grade (~100% functional)

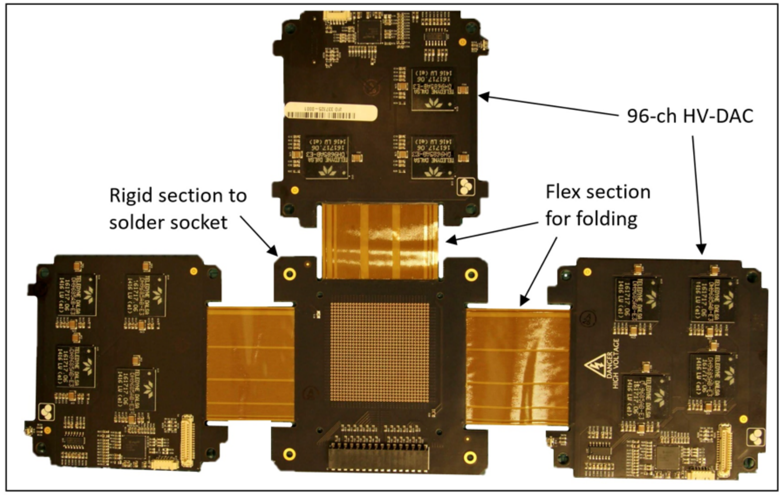
Kilo DMs

Robust, flight-capable DM electronics tested in HCIT and PICTURE-C

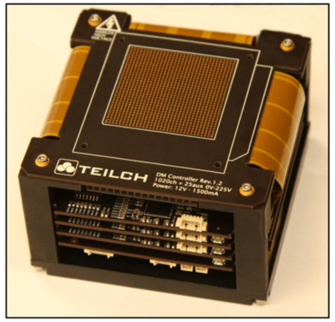


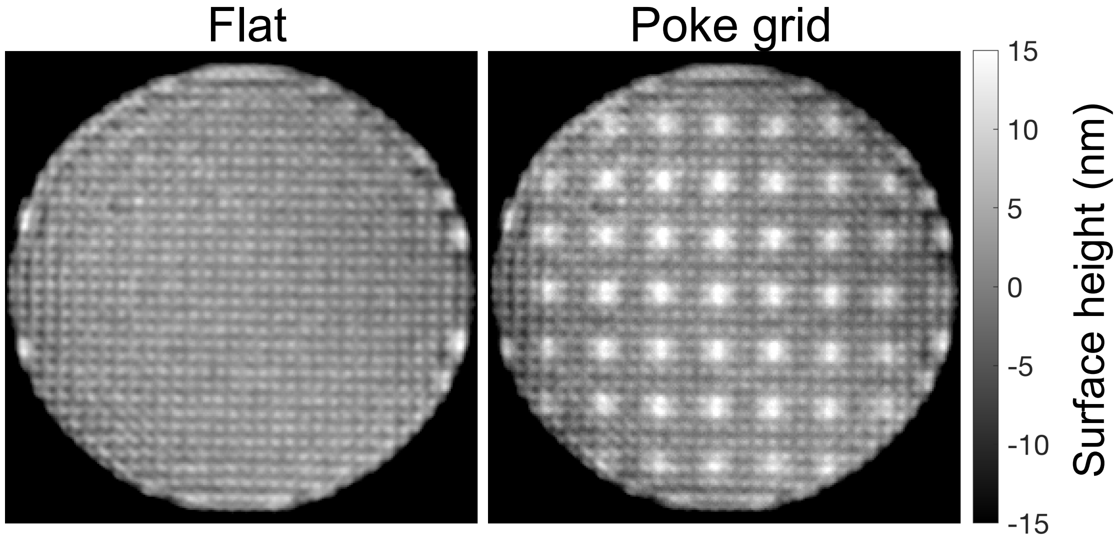
USB-controlled electronics for BMC Kilo DMs.
10x10x5 cm format. Manufactured by Teilch.
2K version under development.

Miniaturized DM Controller unfolded flex-rigid PCB



Miniaturized DM Controller after folding



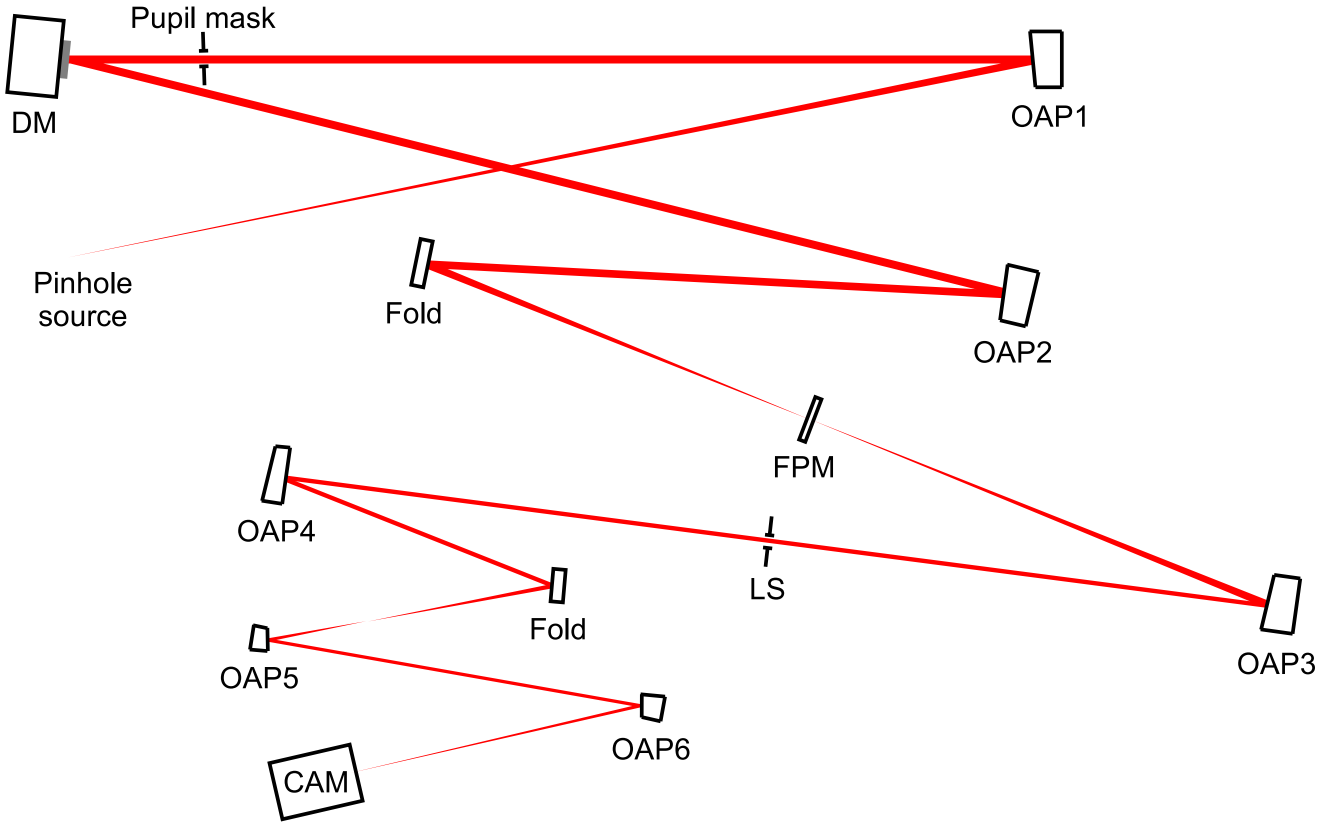


Three of our Kilo DMs have 100% responsive actuators

Bendek et al., 2020, JATIS, in press.

We achieved <1e-8 contrast with the Teilch controller on the GPCT

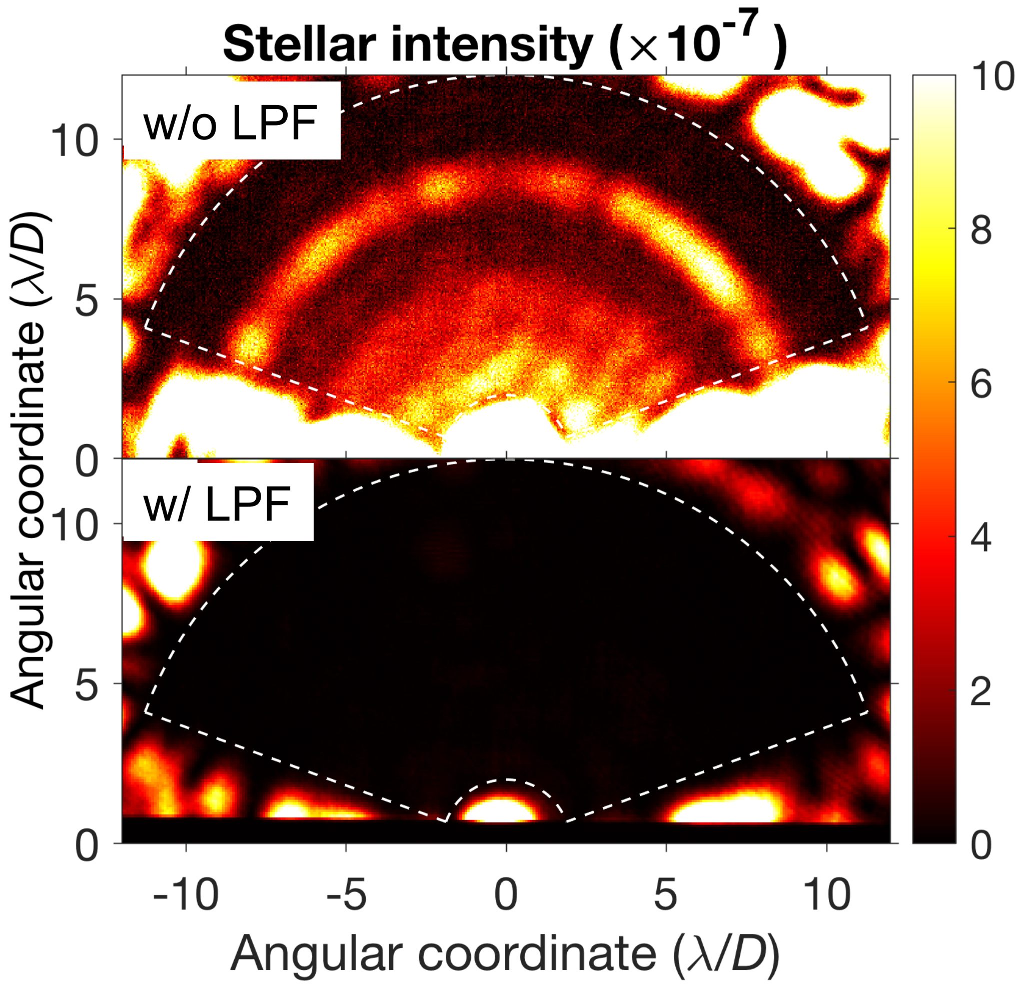
Schematic of the GPCT

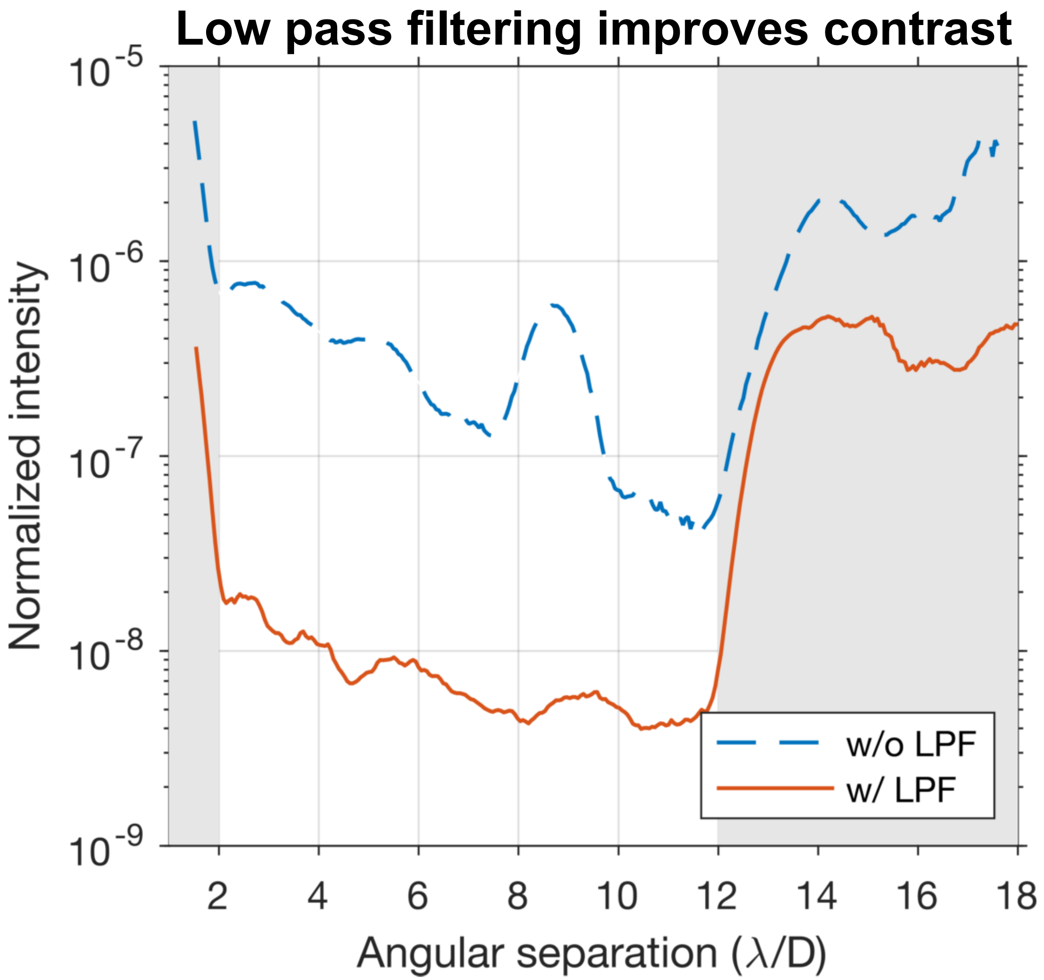


- Coronagraph testbed formerly in the HCIT-2 vacuum chamber.
- Originally used to test vector vortex coronagraph masks.
- Achieved <1e-8 contrast with Teilch controller.
- GPCT will be set up outside of the vacuum chamber for MEMS DM testing in air.
- Teilch controller was tested on GPCT and is now installed on the PIAACMC testbed (PI: Belikov).

Lesson learned: electronic noise → temporal incoherence

Using **x029** (our best Kilo DM) and the Teilch controller with and without low pass filtering

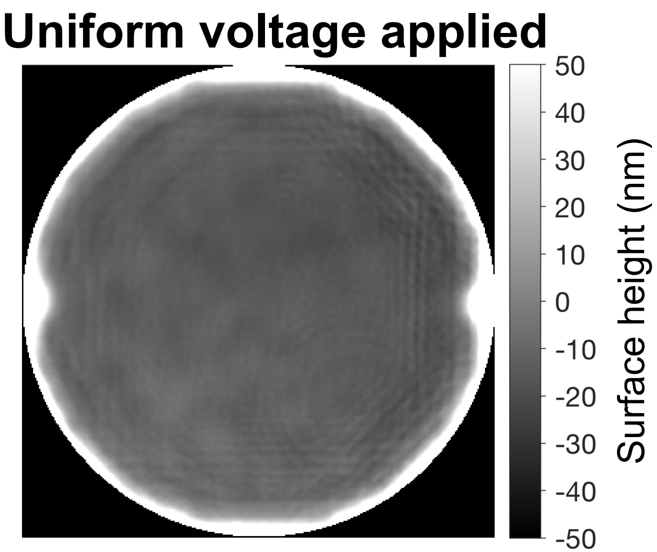




Bendek et al., 2020, JATIS, in press.

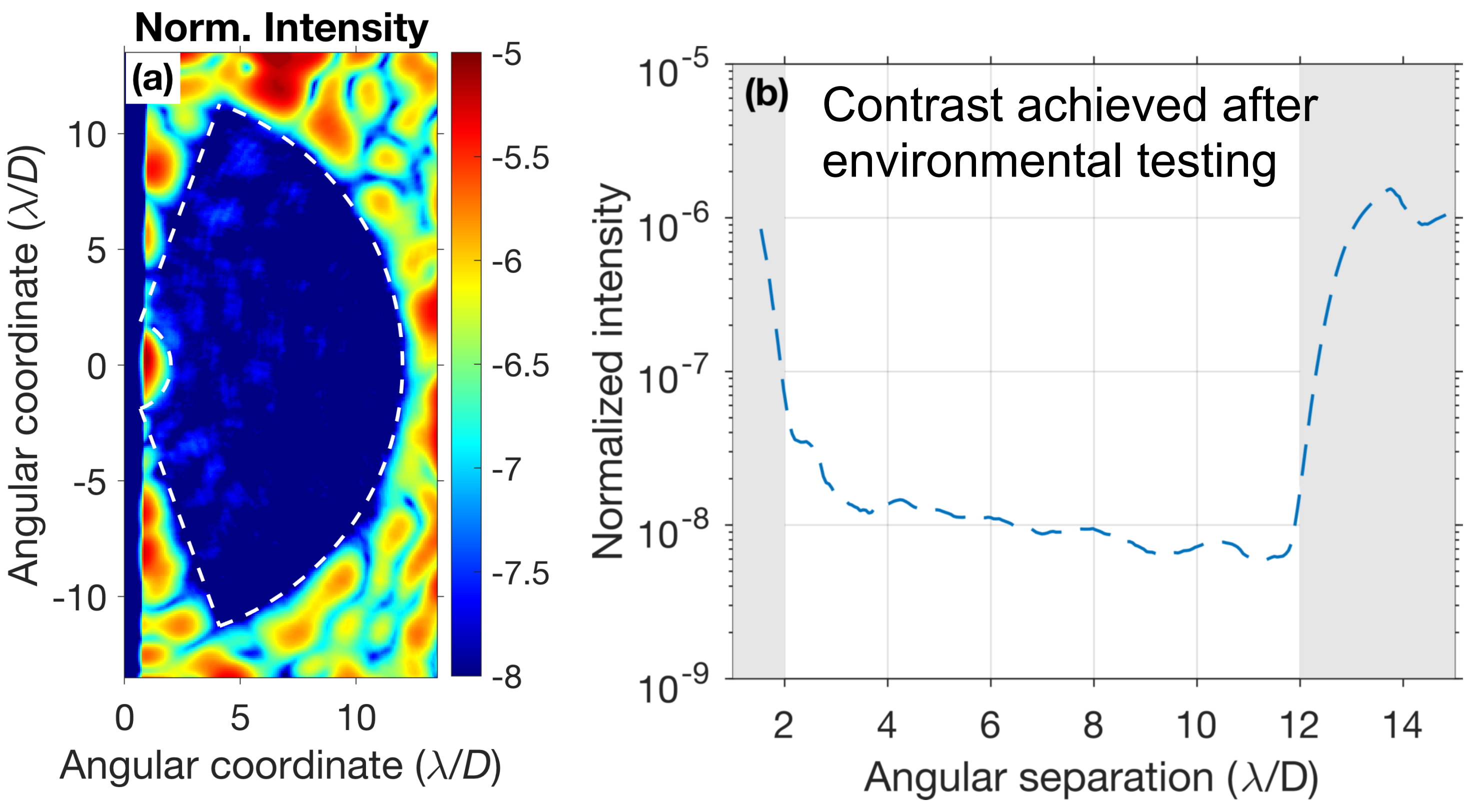
Kilo DMs performed well after random vibration testing

x015 and **x035** had 100% actuator response after random vibe testing.



interferometer measurement

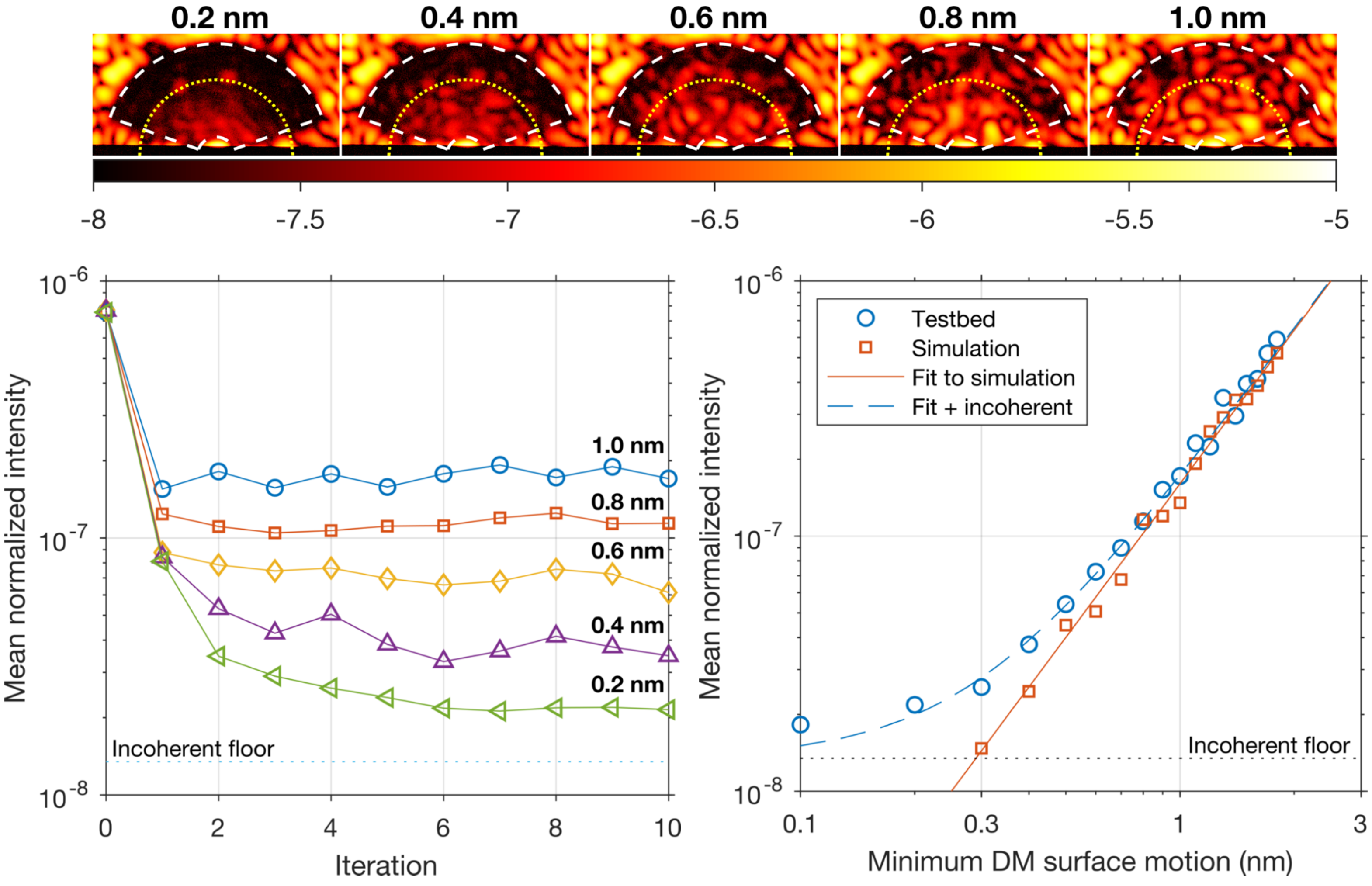
Using **x015** after random-vibe and the Teilch controller on GPCT in vacuum, we achieved 1e-8 contrast.



Results delivered to Paul Bierden (BMC) as part of a NASA SAT/TDEM study

Empirical DM surface height resolution requirements

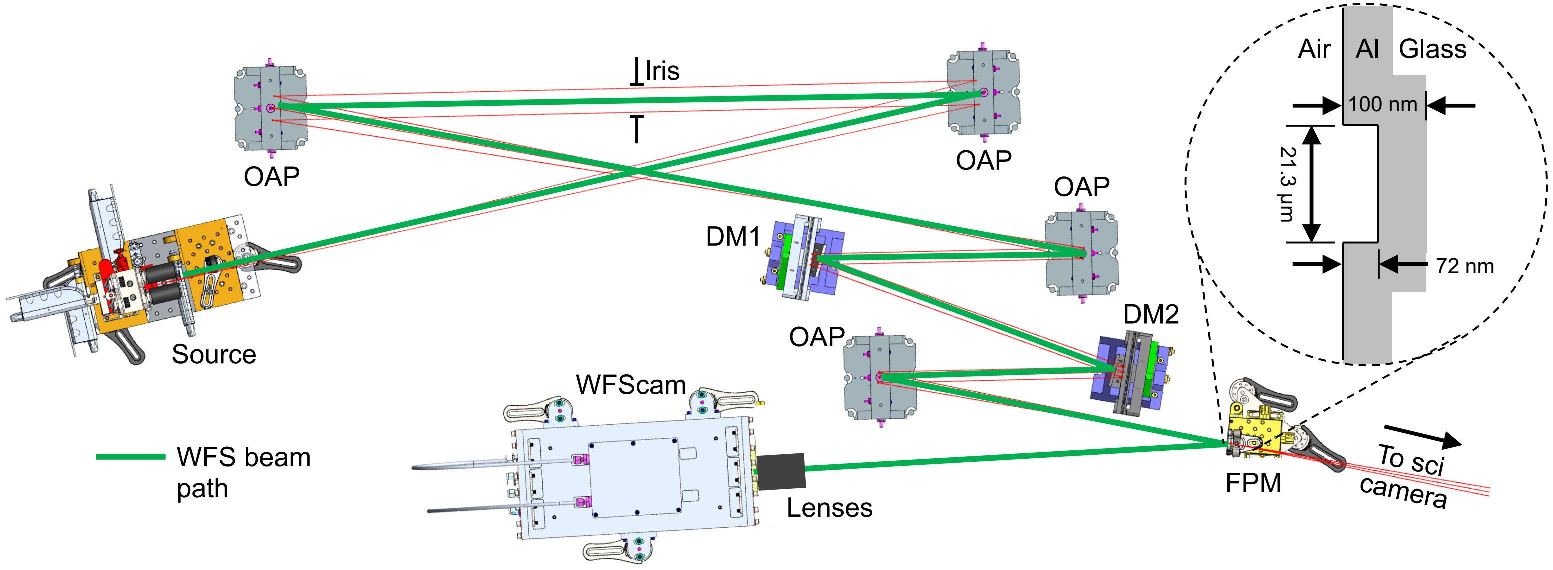
- Injected artificial quantization errors during wavefront control on GPCT.
- Validated analytical and numerical models, which can be used to set robust requirements.
- Key finding: overly-simplified analytical models can lead to artificially relaxed requirements on the DM surface height resolution.
- DM surface height resolution of <6 pm for HabEx/LUVOIR.

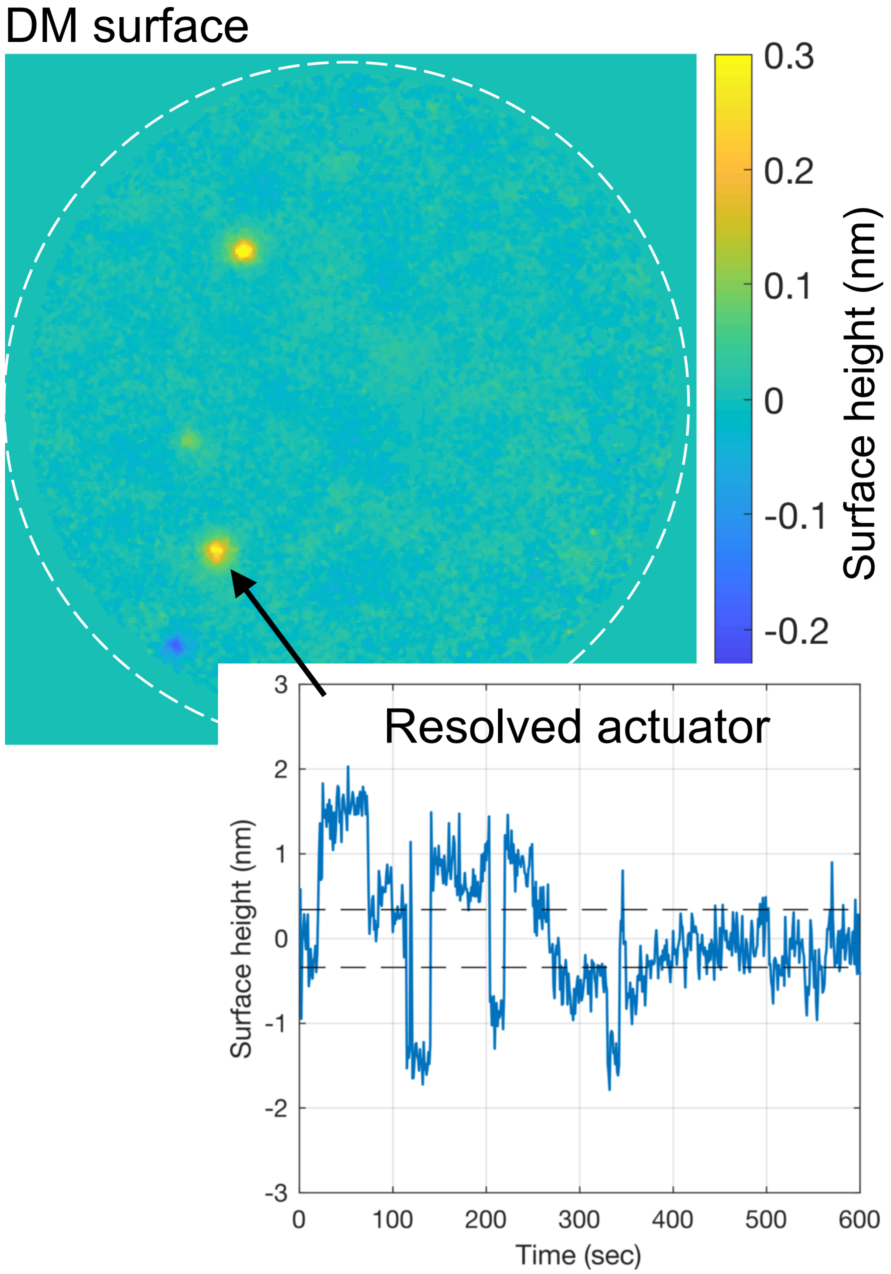


Ruane et al., 2020a, JATIS, in press.

2K DMs

Zernike wavefront sensor directly identifies rogue actuators





- *in situ* high-order wavefront sensor
- ZWFS used to identify noisy channels in the DM electronics
- Closed loop control demonstrated
- Picometer sensitivity achieved (after temporal binning)
- Key technology for future missions (e.g. HabEx/LUVOIR)

Ruane et al., 2020b, JATIS, under review

2K MEMS performance demonstrated on DST

Test completed

50.B (DM1):
- 10 unresponsive (pinned at 0V)
- 36 tied or weak
- ~10 rogue actuators (pinned)

50.A (DM2):
- “Flat” state

Achieved
2×10^{-9} (best)
4×10^{-9} (typical)

Tests planned

50.A only (DM2 only):
- 26 unresponsive or weakly responding actuators
- Pinned all to 0 V

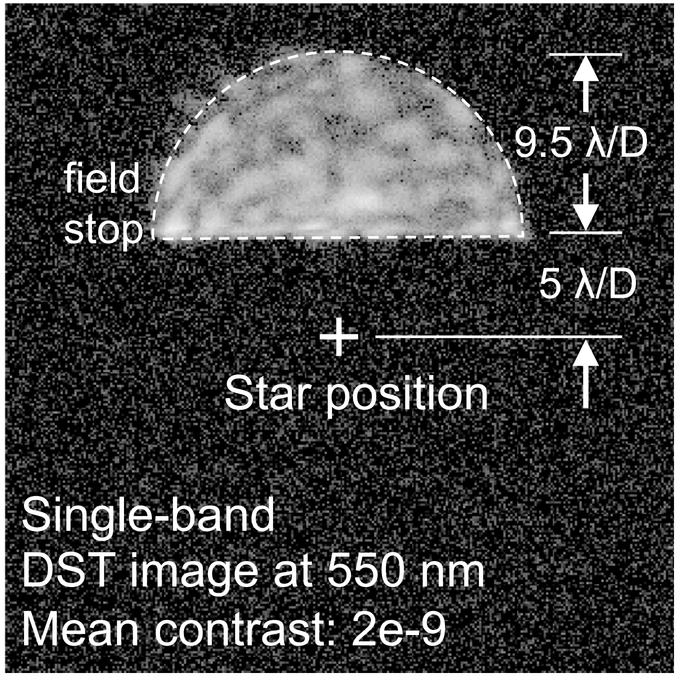
In progress this week ($<10^{-8}$)

50.A + 50.D?

50.D only?

50.D + 50.E?

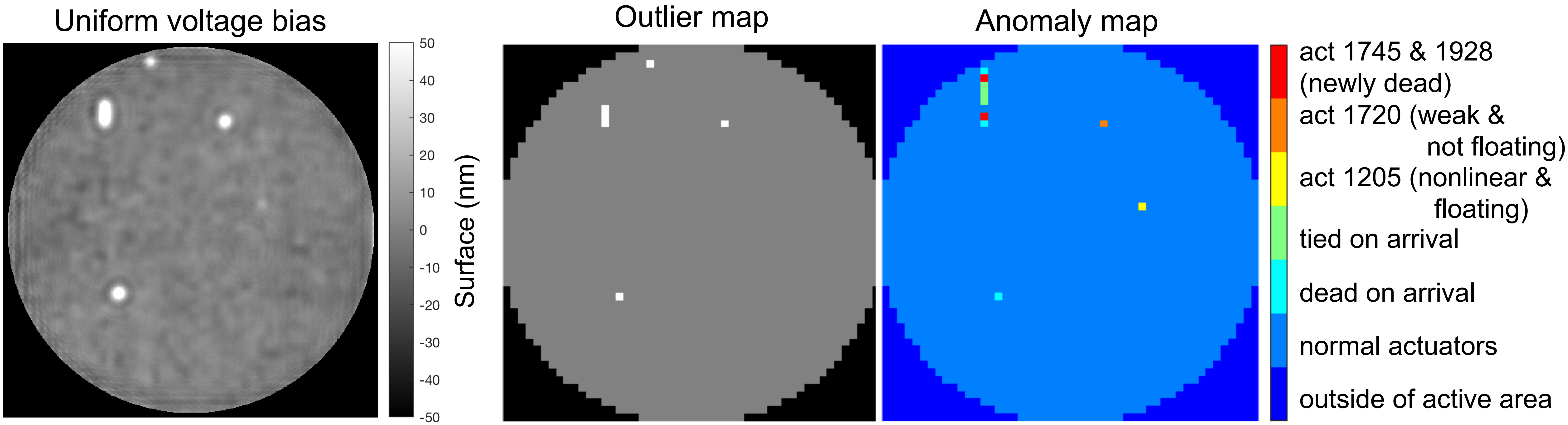
Next step will depend on final outcome of the 50.A tests



Major improvements:
- Low pass filtering (~1e-8 effect)
- Zero-ing rogue actuators (~1e-8 effect)

Environmental testing of BMC 2K DMs

Initial testing was performed on 50.C by CGI project (Sept. 2019)

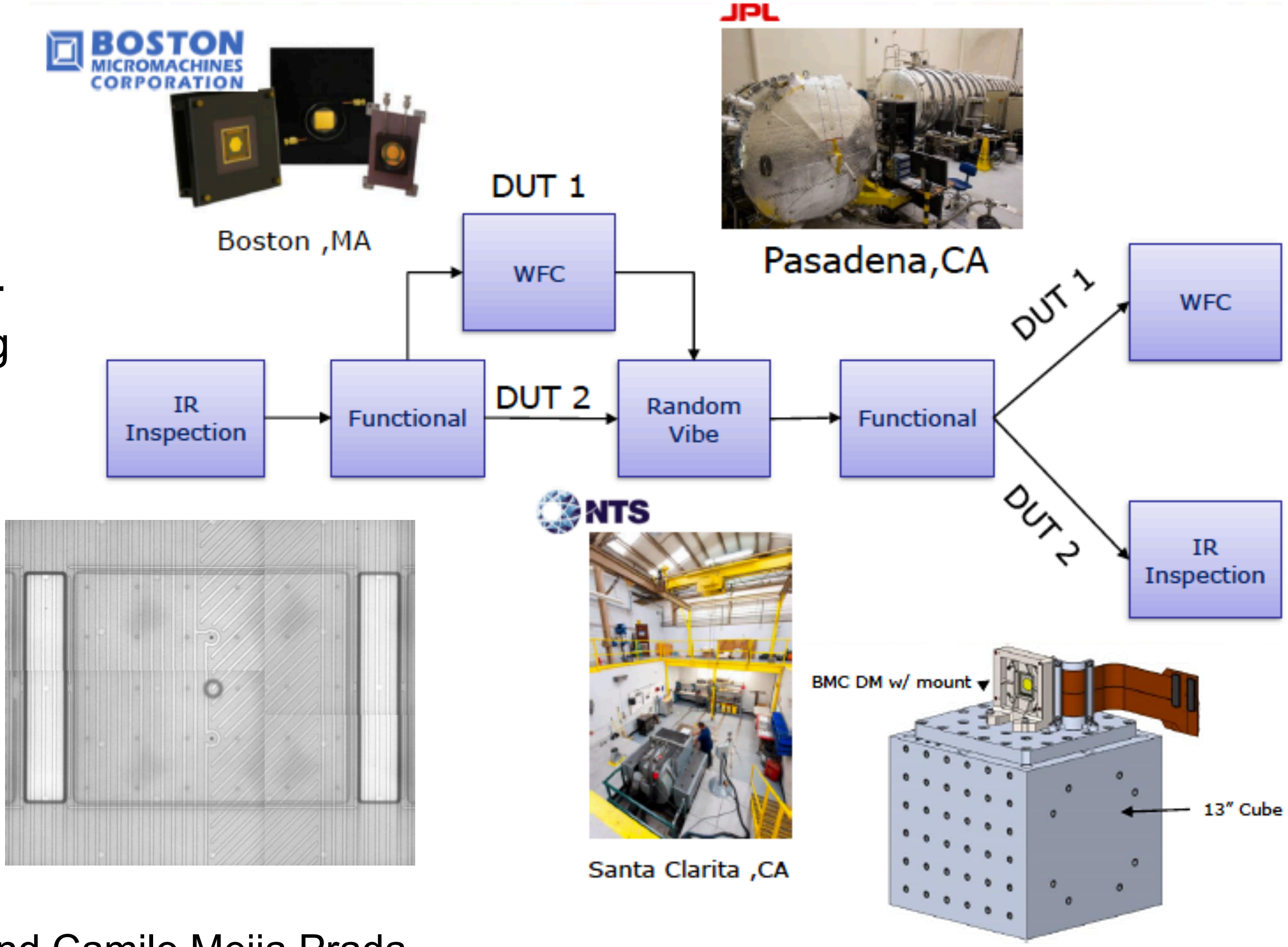


Actuator 1205 was associated with a bent pin on the MEG-array connector and was later recovered.
The two remaining post-vibe anomalies were along a column of previously bad actuators.

Planned environmental testing

Hypothesis: Post-vibe anomalies are associated with defects

- Two 2K units:
  - DUT1: science grade, Al coated
  - DUT2: few bad actuators, uncoated to allow IR microscopy.
- Both will undergo functionality testing using an interferometer.
- DUT1 will be installed on the “in-air” GPCT to demonstrate a dark hole before and after random vibe.

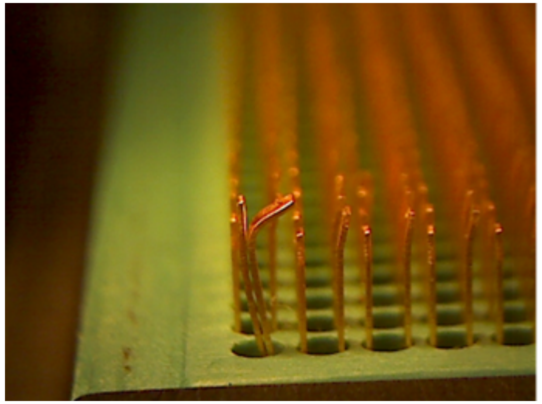


Study supported by ExEP, led by Bob Peters and Camilo Mejia Prada

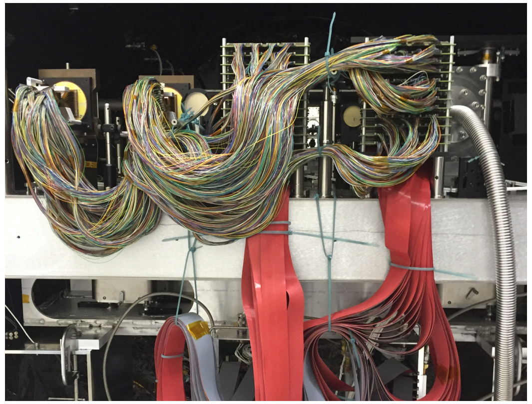
Outstanding challenges

Connectorization

- Channel connections at all levels (boards, cables, DM socket) have caused problems.
- Problems grow with number of actuators for same reliability per actuator.
- Connections can change every time the system is re-connected. Thus, debugging the electronics is very difficult without more reliable connectors.
- There is an opportunity to learn from deformable secondary mirrors in ground-base telescopes (e.g. ELTs where up to 8000 channels are planned).



Bent pin on a BMC Kilo DM socket



Cabling for Xinetics DM at JPL's High Contrast Imaging Testbed (HCIT)

Electronics

- The Teilch controller testing was successful
  1) Connections are minimized
  2) Use of large-count ASIC (96 Channel each)
- Scaling up is a challenge as 96 Channel ASIC went out of production.
- Custom ASIC seems to be a must for flight on future flagship.
- ASIC development should be continued.

Environmental testing

- Radiation testing at component or system level has not been addressed.
- Continue rad-hard ASIC development.
- Perform radiation testing on the DM itself.
- Contamination control proven to be an challenge for MEMS DM.
  - See KODIAK (Mirrocle MEMS for space LIDAR)
  - BMC SAT DM testing at Princeton