Recent Progress in MEMS Deformable Mirrors

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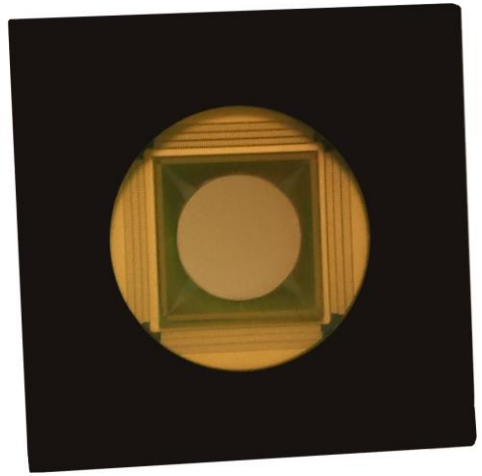
BOSTON MICROMACHINES CORPORATION
SHAPING LIGHT

Mirror Technology/SBIR/STTR Workshop 2018
Wednesday, Nov 7

SPIE.
CONNECTING MINDS. ADVANCING LIGHT.

Outline

- BMC DM Technology
- NASA funded mirror technology programs
- Astronomy Applications



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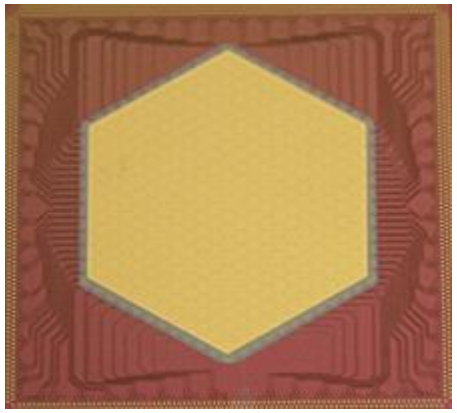
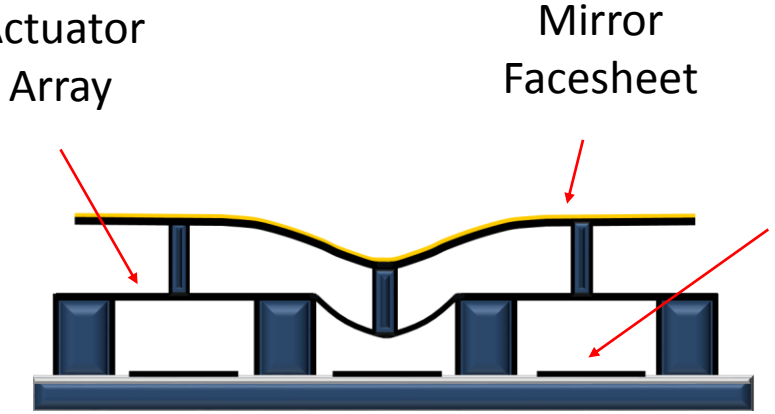
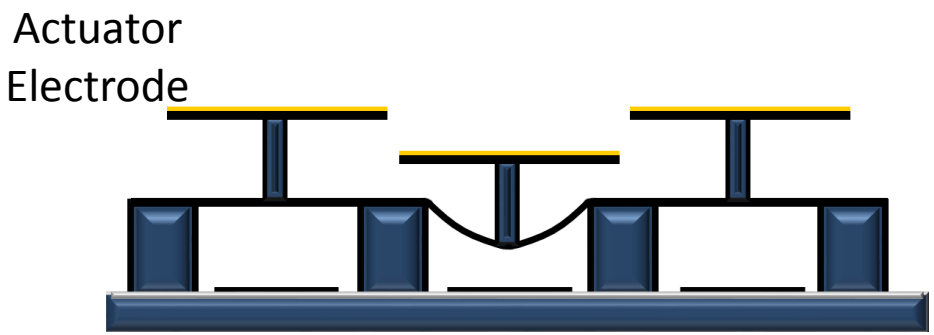


MEMS DM Architecture

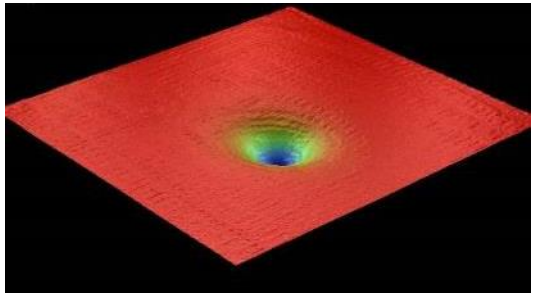


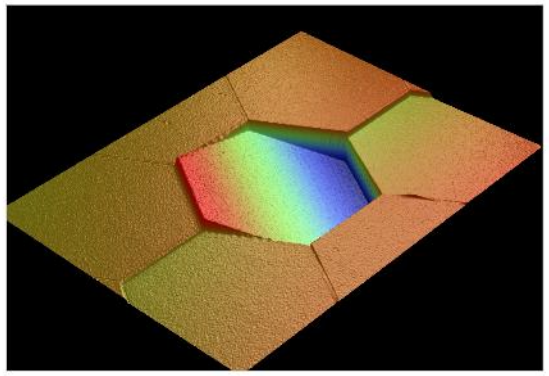
Continuous mirror
(smooth phase control)



Segmented mirror
(uncoupled control)

Hex Tip-Tilt-Piston





BMC Mirror Family

Small Cartesian Arrays

- Square arrays from 32 to 140 actuators
- Strokes: 1.5µm, 3.5µm or 5.5µm

Medium Cartesian Arrays

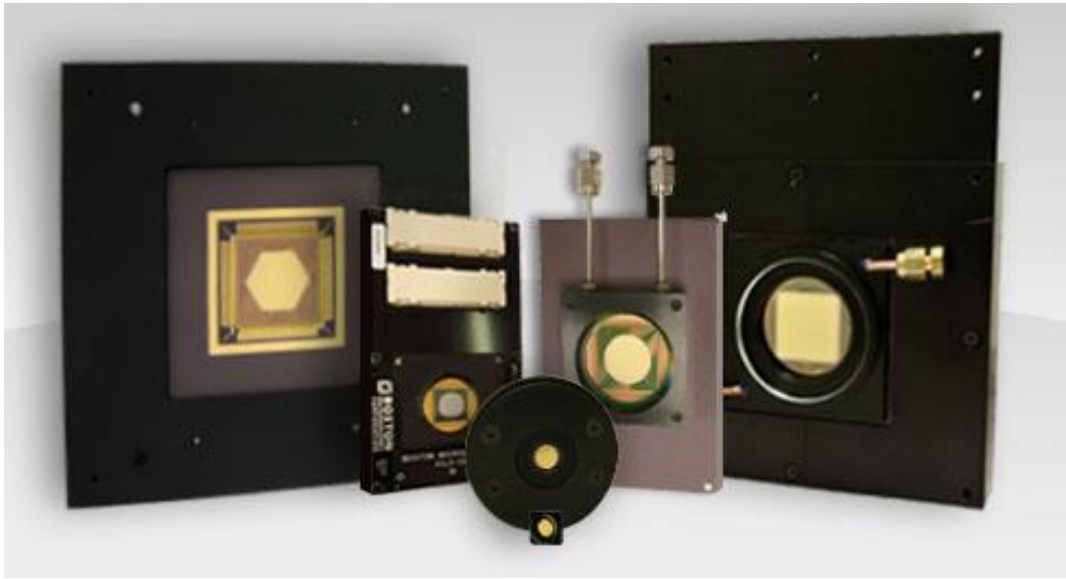
- Square and circular arrays from 492 to **1020**
- 1.5µm & 3.5µm stroke

Large Cartesian Arrays

- Square and circular arrays from **2040** to 4092
- 1.5µm and 3.5µm stroke

Hex Tip-Tilt-Piston

- 37, **331- and 1021-Segment Devices**



Developed through NASA funding

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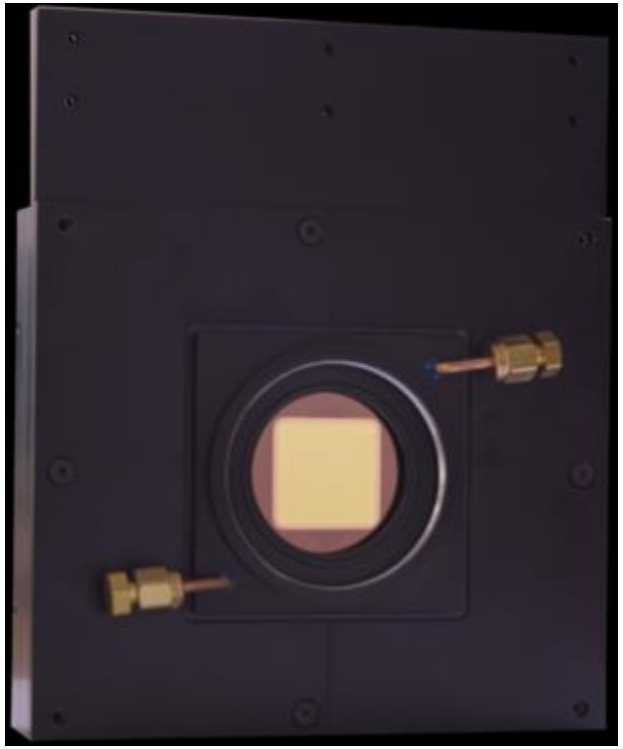
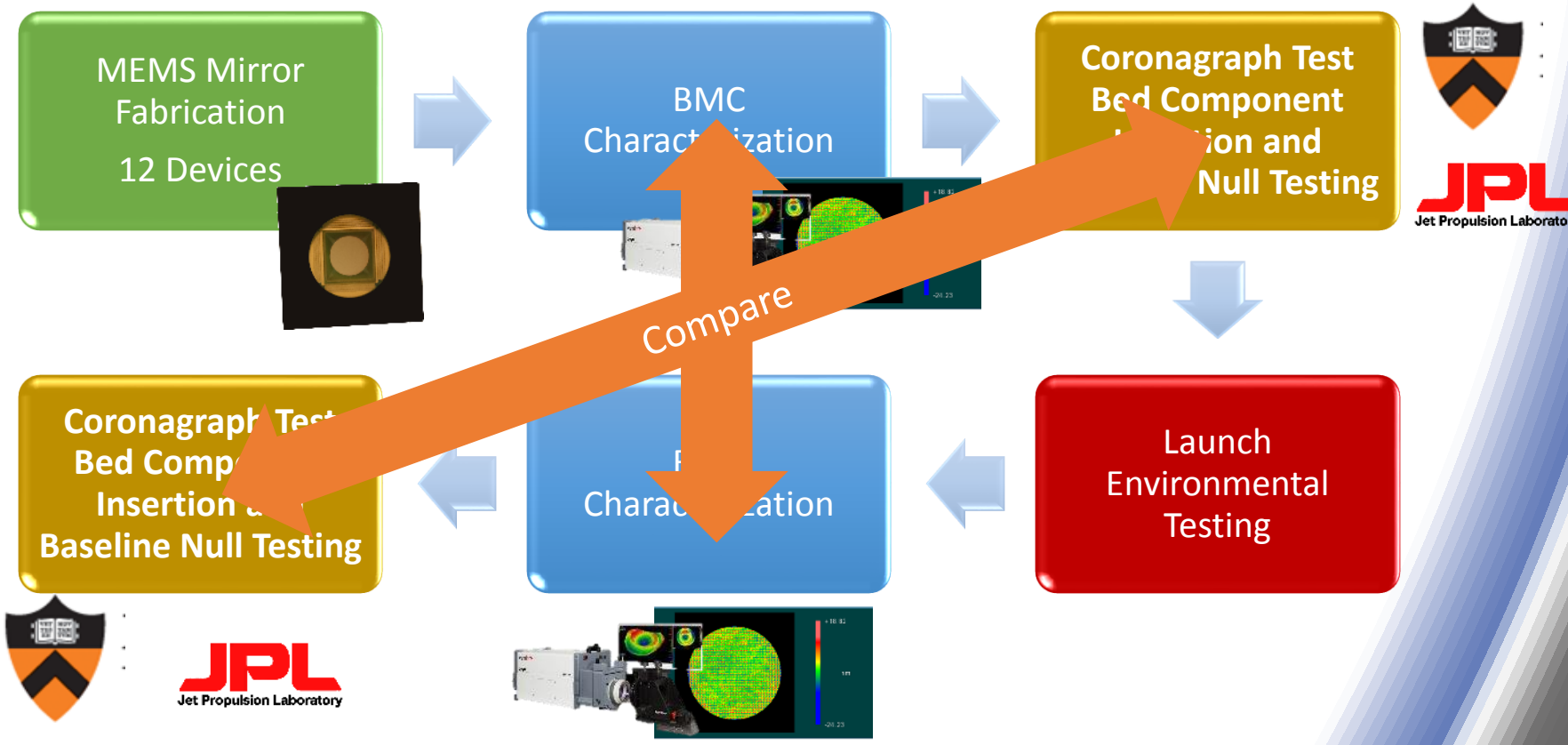


MEMS Deformable Mirror Technology Development for Space-Based Exoplanet Detection

Contract#: NNH12CQ27CSAT/TDEM

Objective: Demonstrate survivability of the BMC MEMS Deformable Mirror after exposure to dynamic mechanical environments close to those expected in space based coronagraph launch.



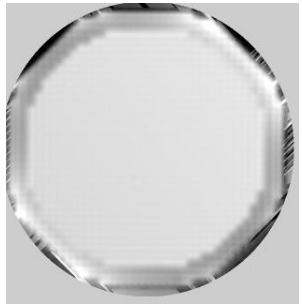
Testing at JPL VSG

Flattened

6.6nm PV focus,
2.9nm PV 45 deg astig, 0.3nm
PV 90 deg astig, 7.6nm RMS
higher order terms

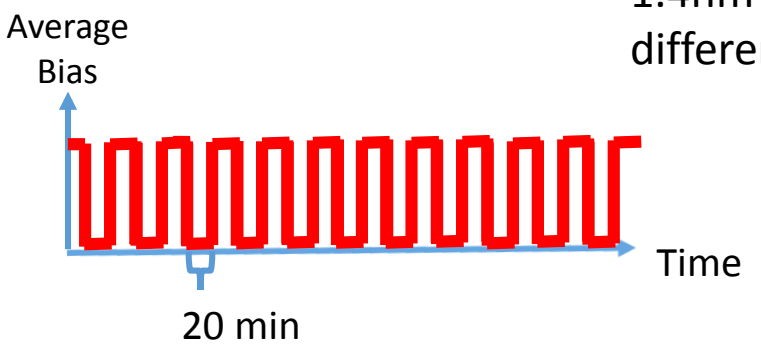
Repeatability

Initial

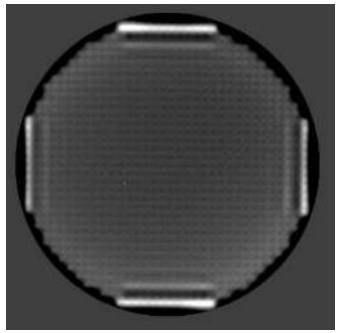


Final

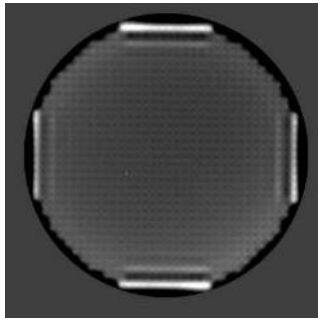
1.4nm RMS difference



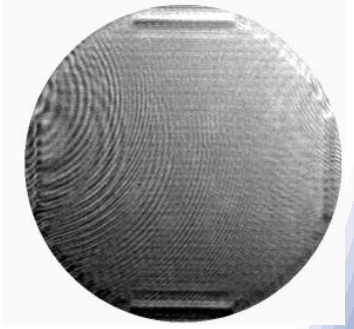
Stability



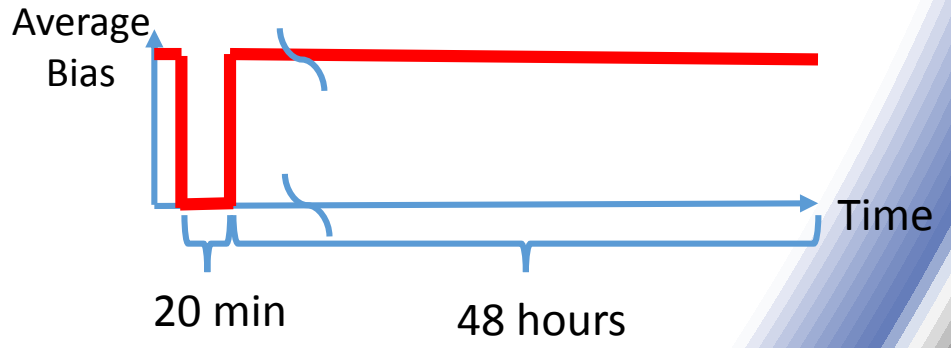
Initial



Final



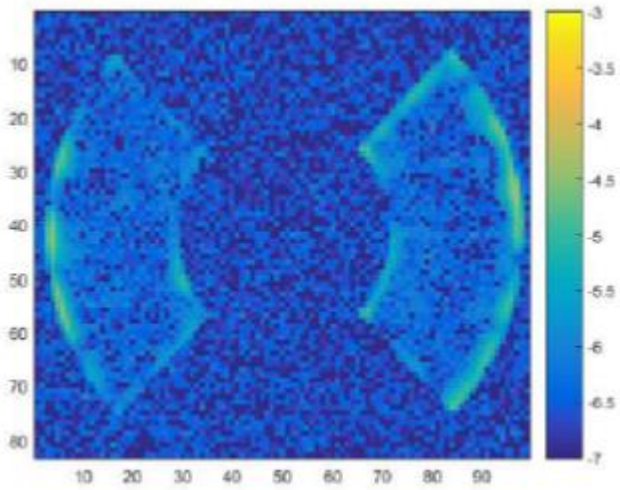
0.9nm RMS difference



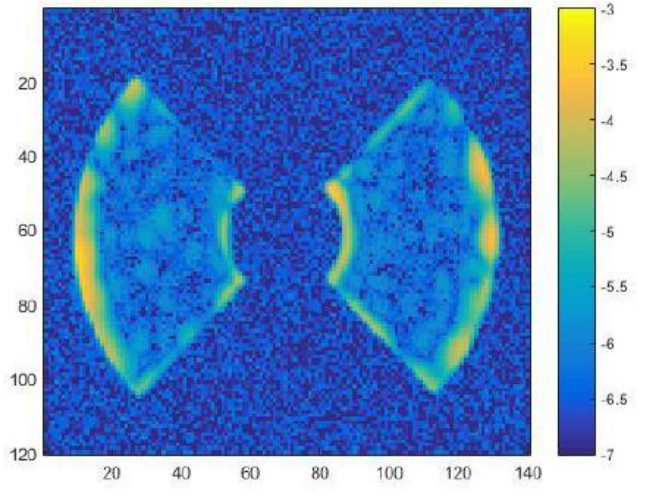
High Contrast Imaging Laboratory(HCIL)

Kasdin Lab, Princeton University

- Batch process estimator with two pairs of probes
- Stroke minimization controller
- Two BMC DMs with 952 actuators on each
- Achieved 2 x 10^{-7} contrast within 6-11 λ/D and 9 x 10^{-7} contrast 5-14 λ/D



6-11 λ/D

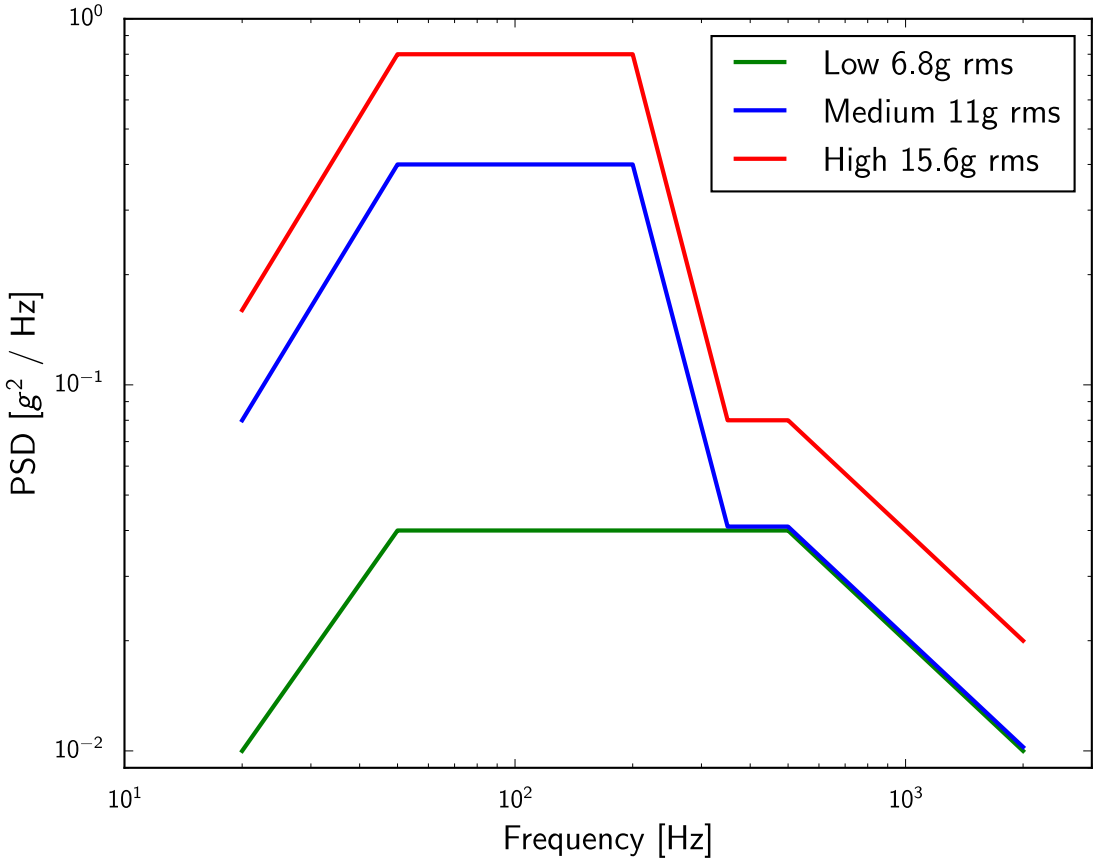


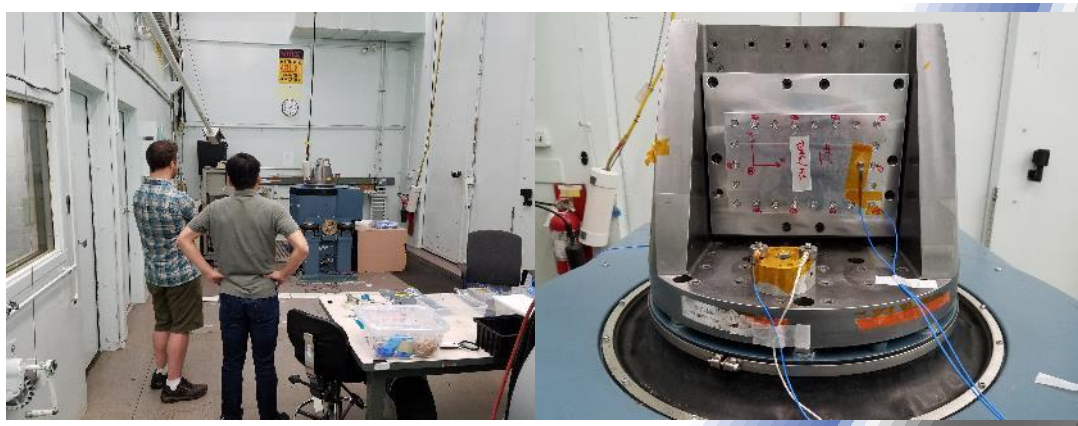
5-14 λ/D

PRINCETON UNIVERSITY

Vibration Testing for TDEM

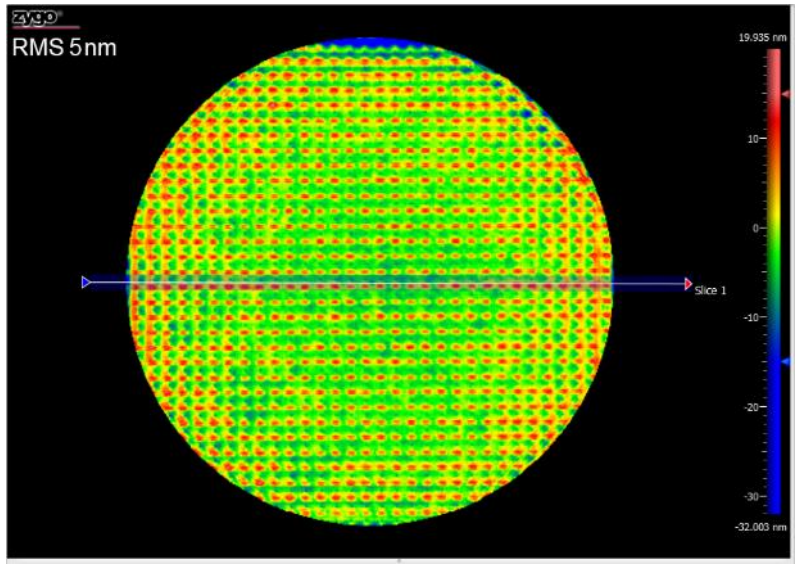
- Levels defined by WFIRST
- 9 DMs were tested
  - 3 Low Level
  - 3 Medium Level
  - 3 High Level
- 1 DM traveled to Goddard and back but was not exposed to vibration
- 1 DM stayed at BMC
- All DMs were characterized at BMC before going to Goddard





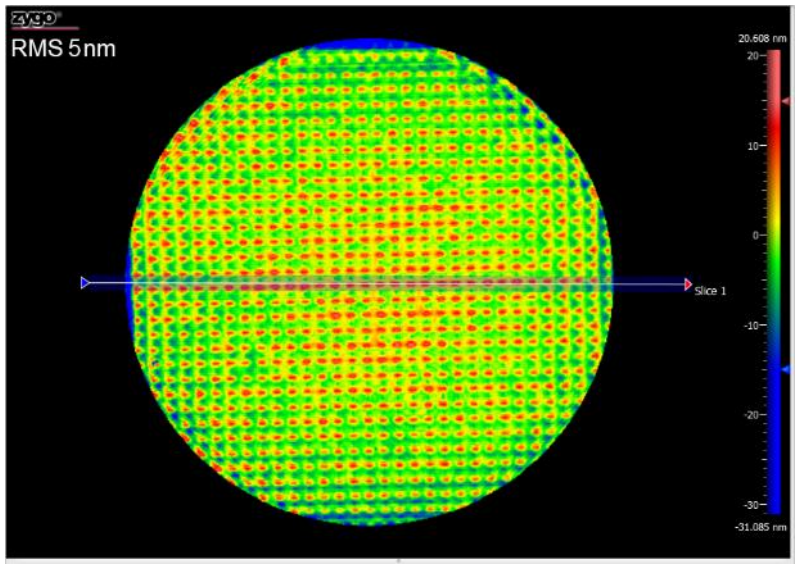
Example Results

Pre Vibe Flattening



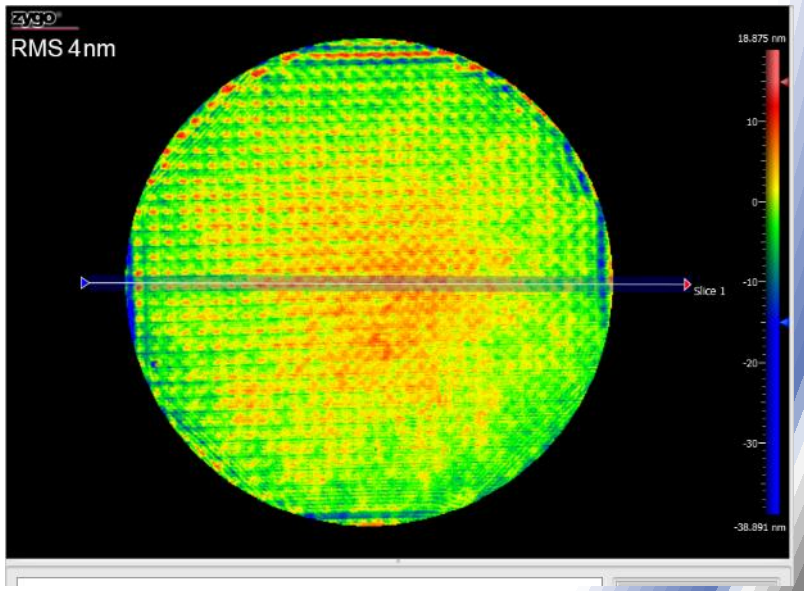
5nm RMS

Post Vibe Flattening



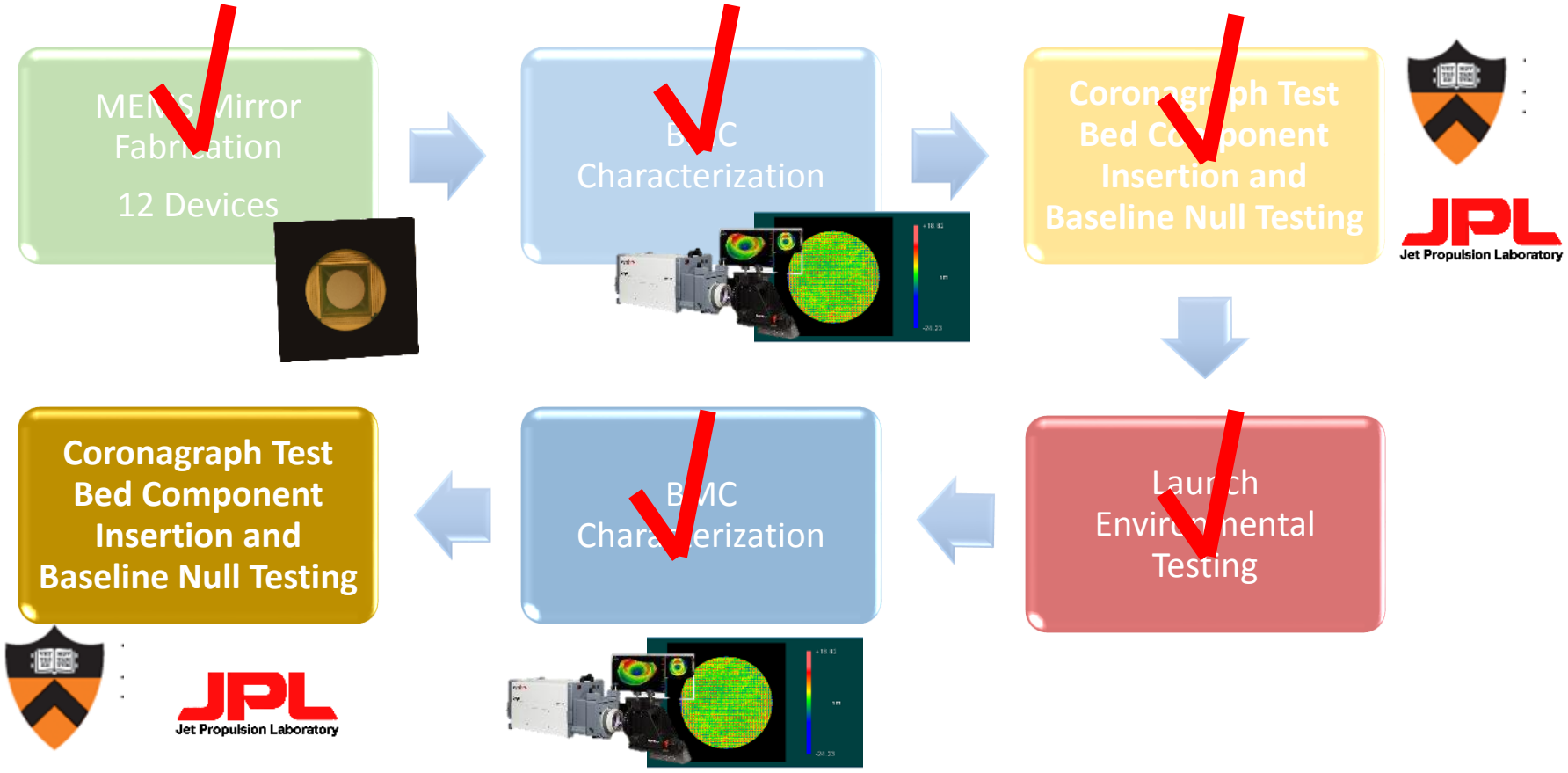
5nm RMS

Difference



4nm RMS

Project Flow



Improved Yield, Performance and Reliability of High-Actuator-Count Deformable Mirrors

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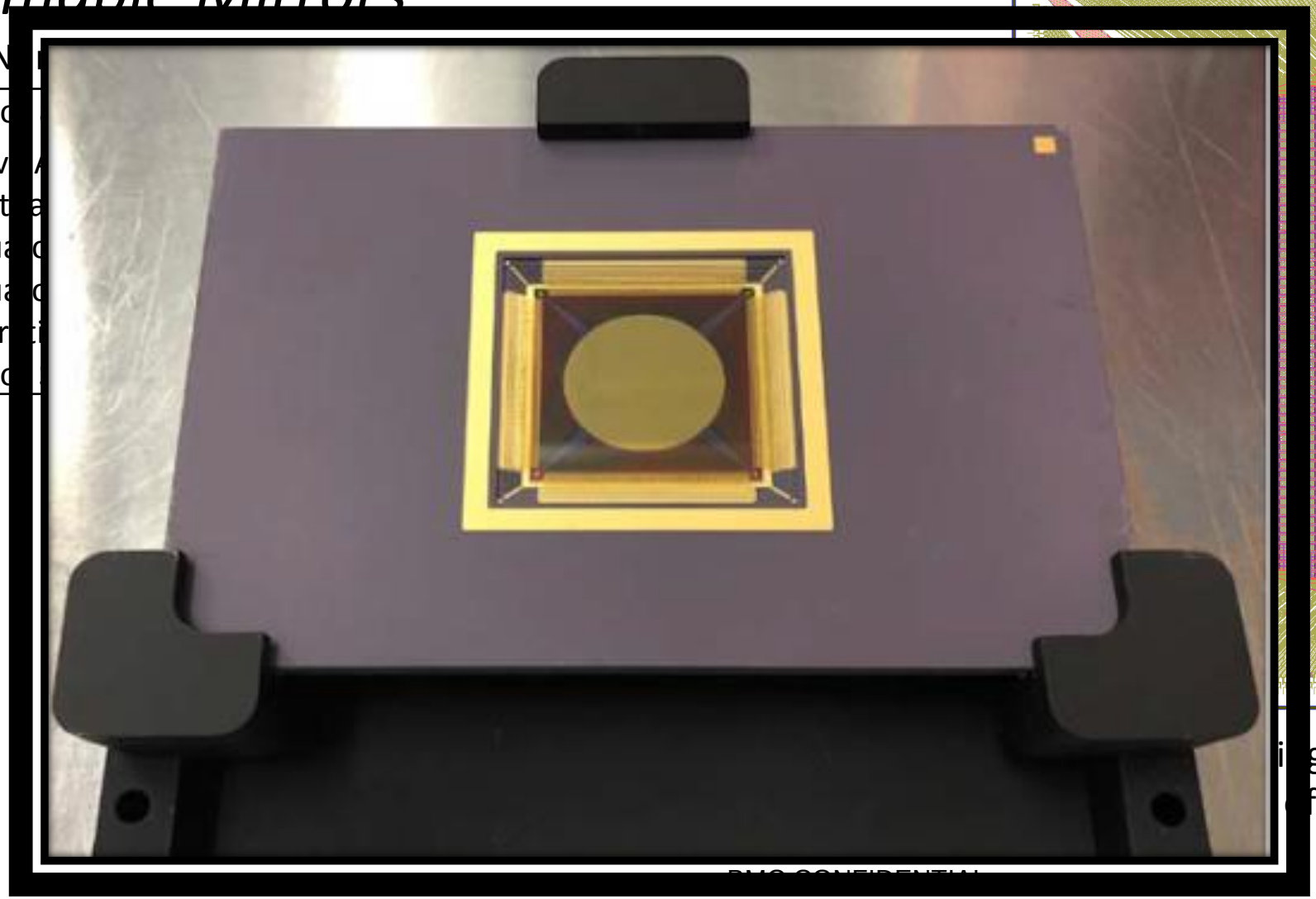
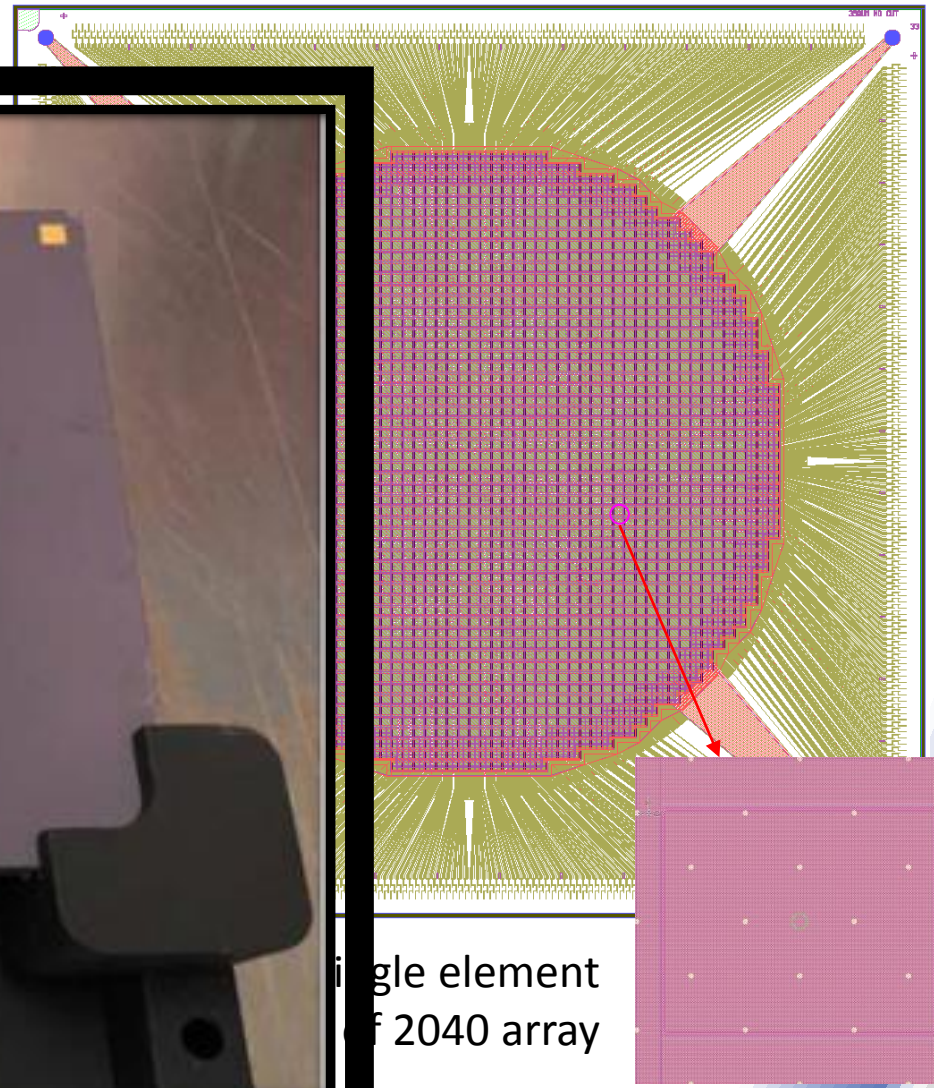
Oper	ti
Mirro	



2K DM Die Layout

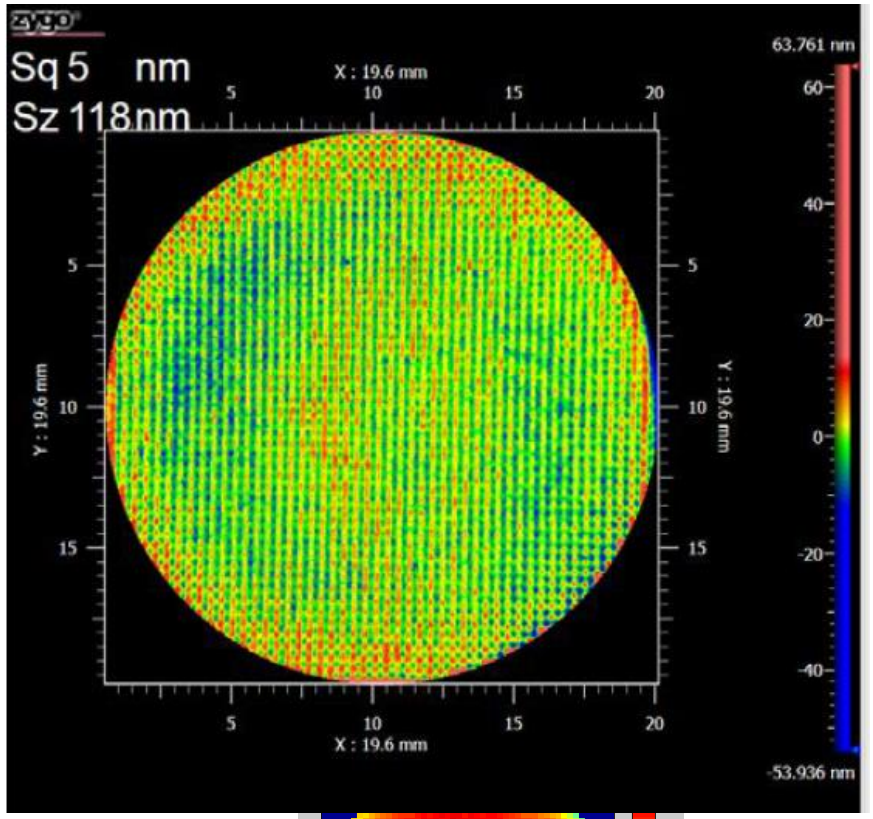


gle element
f 2040 array

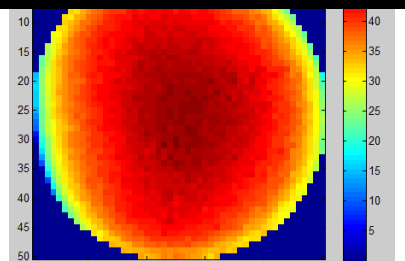
Phase II 2K DM Status

Actively Flattened

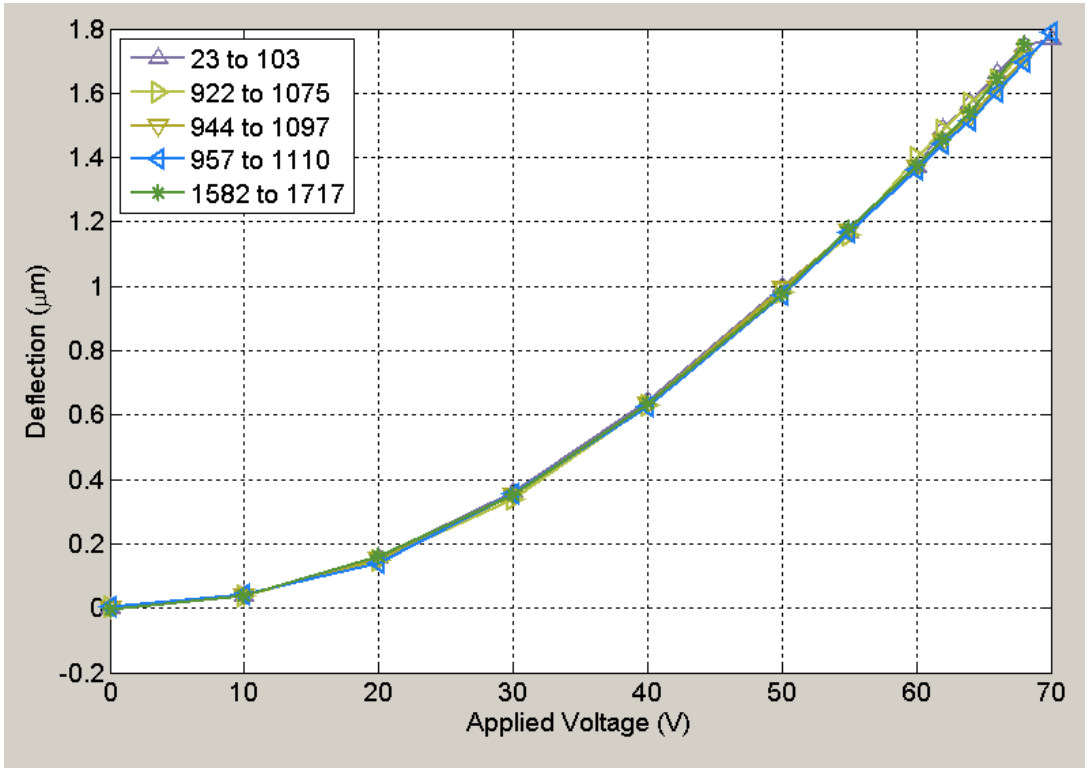
- 5 nm RMS



Voltage map for flattening DM



Voltage vs. Deflection Test

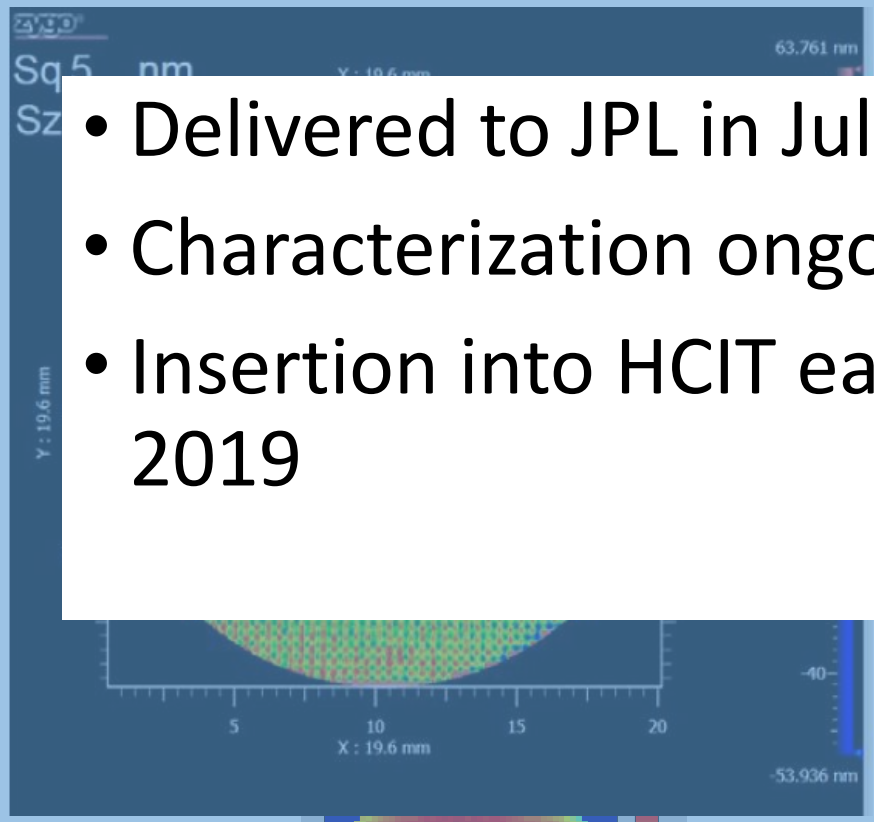


Low Voltage Design

Phase II 2K DM Status

Actively Flattened

- 5 nm RMS



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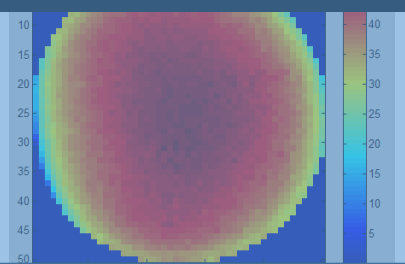
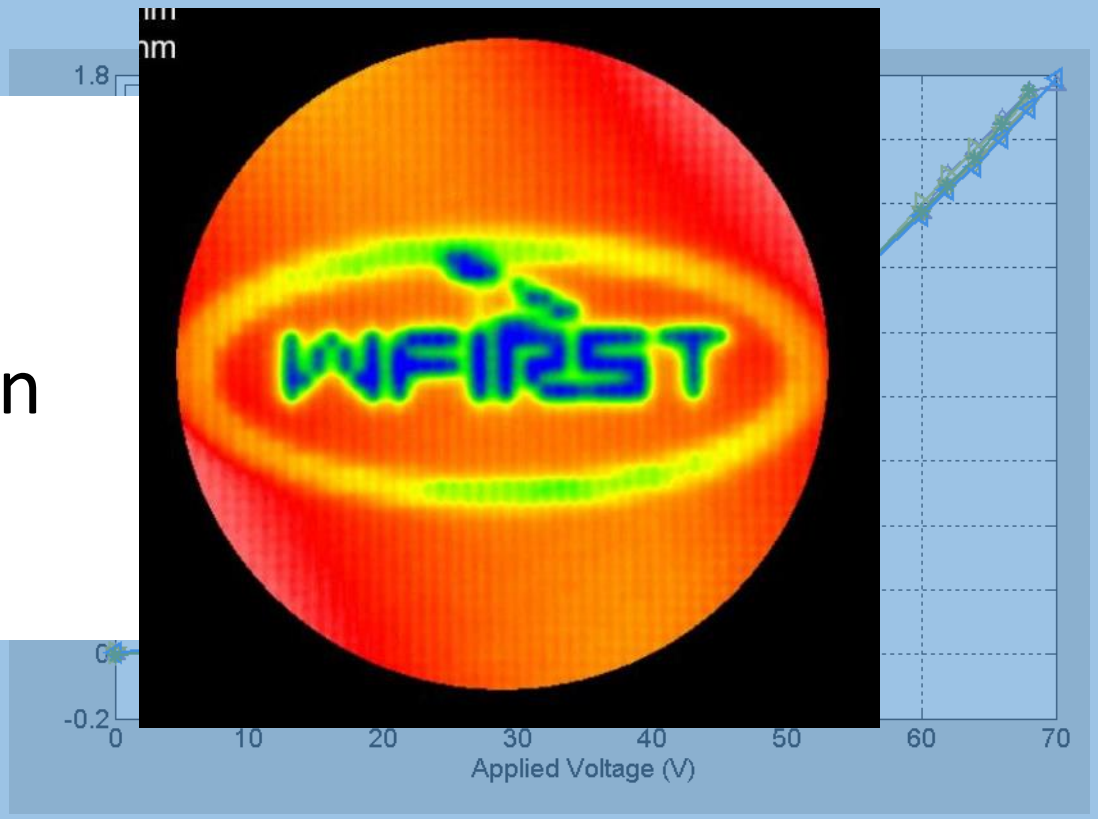


- Delivered to JPL in July
- Characterization ongoing
- Insertion into HCIT early in 2019

Voltage vs. Deflection Test



Low Voltage Design

Phase II-X Program

Goal

- Deliver two 2040 actuator DMs with 100% functioning actuators
- Extensions from Phase II
  - Change substrate thickness to reduce unpowered figure error
  - Use new design developed in Phase II

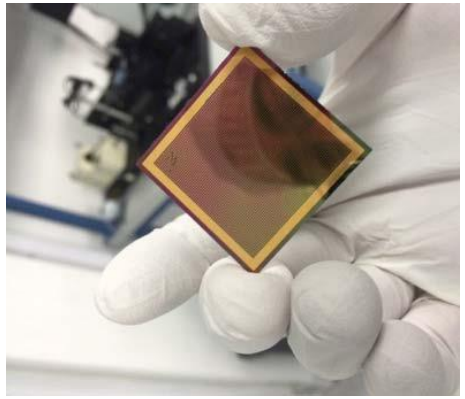
Current Status

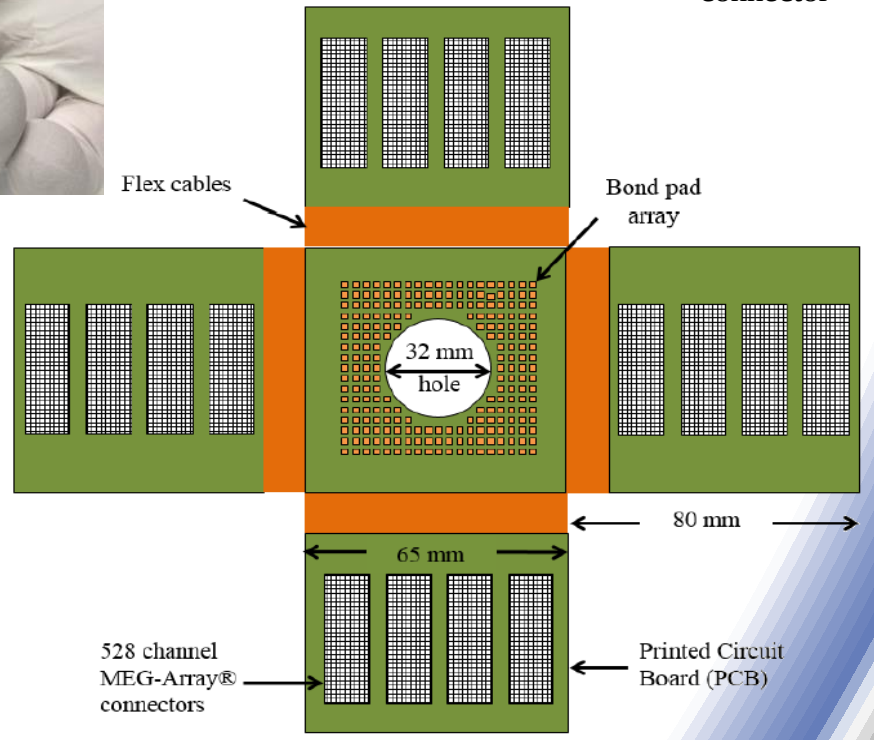
- First fabricated part arriving
- Probe station developed to test yield of devices before packaging
- Starting testing of devices from Phase II

Technology Development for High-Actuator-Count MEMS DM Systems

NASA Contract #NNX17CP76P Phase II SBIR

- Flip chip bonding process where DM is attached directly to flex PCB with high density interconnect
- Packaging and interface design development ongoing
- Proposed for space applications
- Transferable for ground-based applications



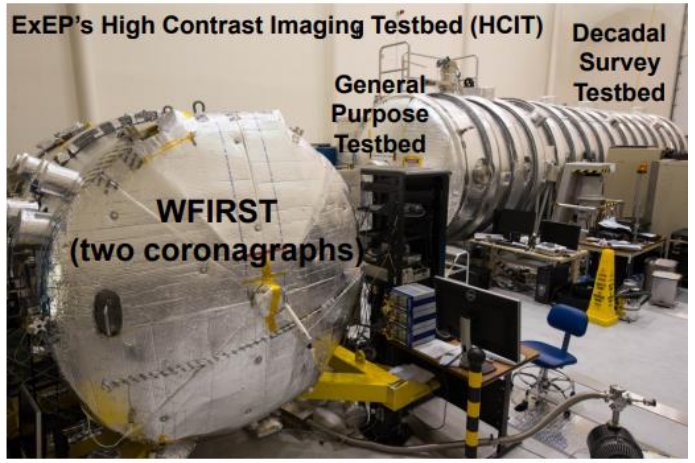


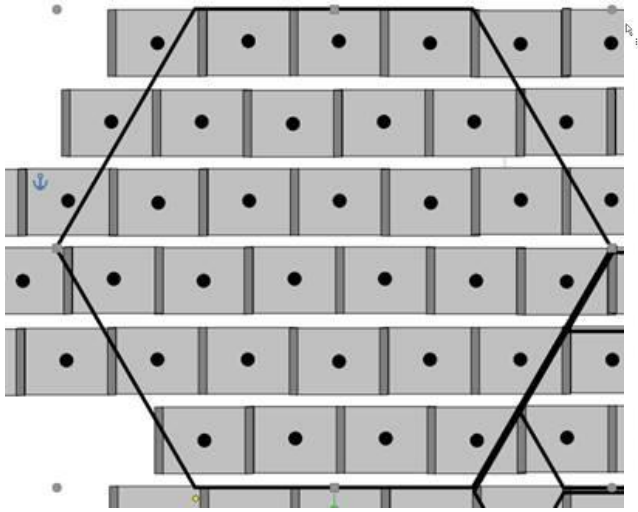
Mirror architecture	7860 actuators
Active Aperture Diameter	29.7mm
# Actuators across active diameter	100
Actuator Pitch	300µm
Actuation architecture	Electrostatic
Actuator Stroke	1.5µm

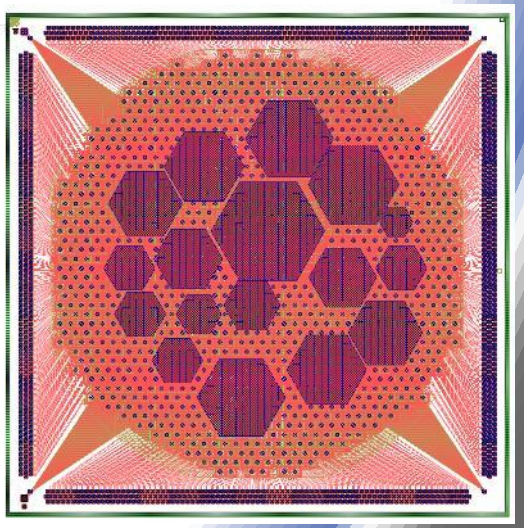
"Primary Tweeters: Segmented micro-mirrors for picometer-scale wavefront compensation in space-based observatories"

NASA Phase I SBIR

- Fabrication of hex deformable mirror that can model segmented primary
- Hex DM segments with range of actuators underneath segment (3,5,8,13…)
- Phase I will evaluate control of varying actuator count
- Phase II will make a DM matching known primary (e.g. JWST, HabEx, LUVIOR)







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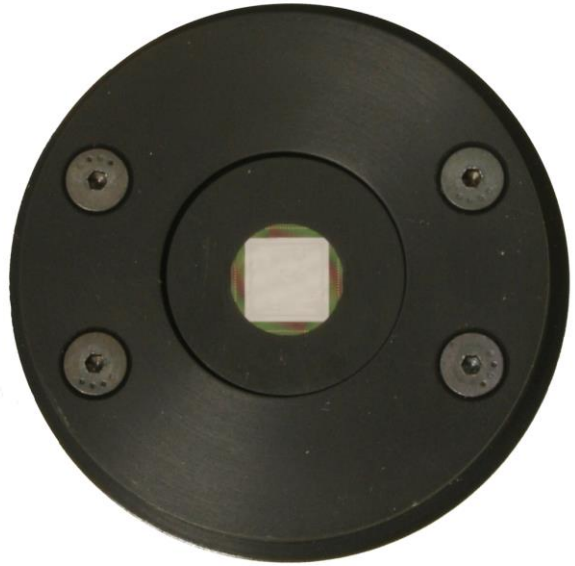
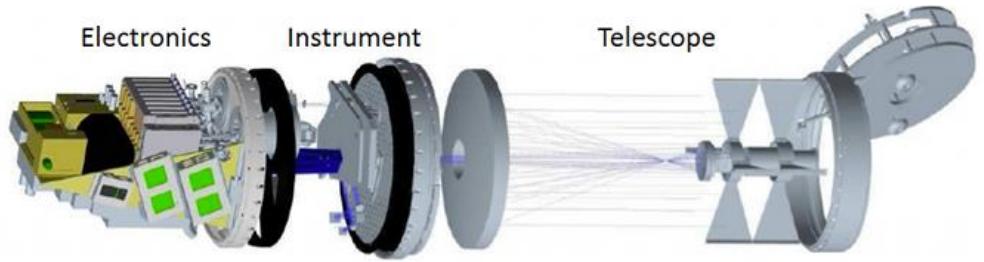


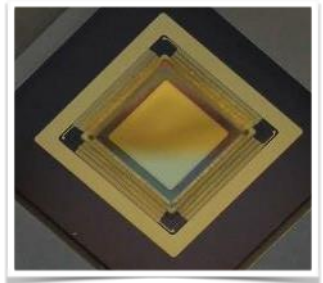
Space Applications

THE PICTURE PROGRAM

PLANETARY IMAGING CONCEPT TESTBED USING A ROCKET EXPERIMENT

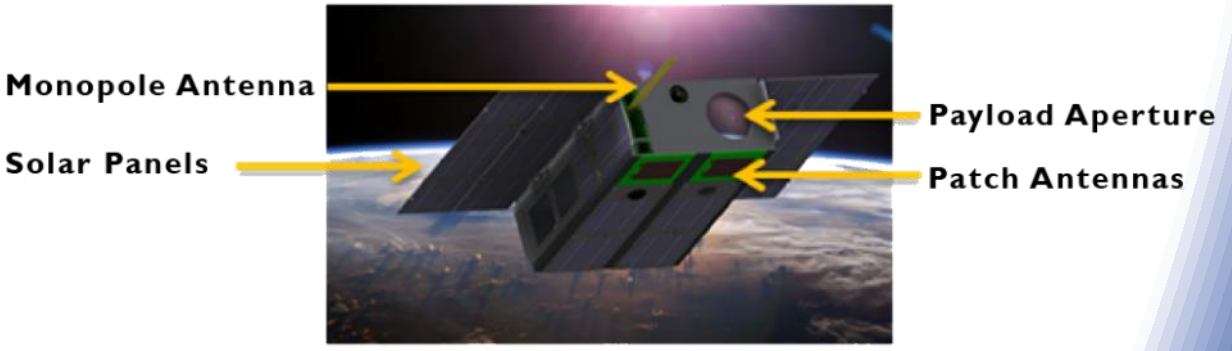
PICTURE	Launched 2011
PICTURE-B	Launched 2015
	Kilo-DM Completed Successful Flight Survivability Test
PICTURE-C	DM Delivered 2017





UMASS LOWELL

DEFORMABLE MIRROR DEMONSTRATION MISSION (DeMi)

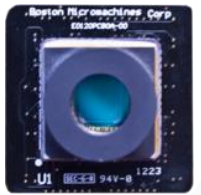


Proposed Mission Configuration

Program Goal:

Validate and demonstrate the capabilities of high actuator count MEMS deformable mirrors for high contrast astronomical imaging.

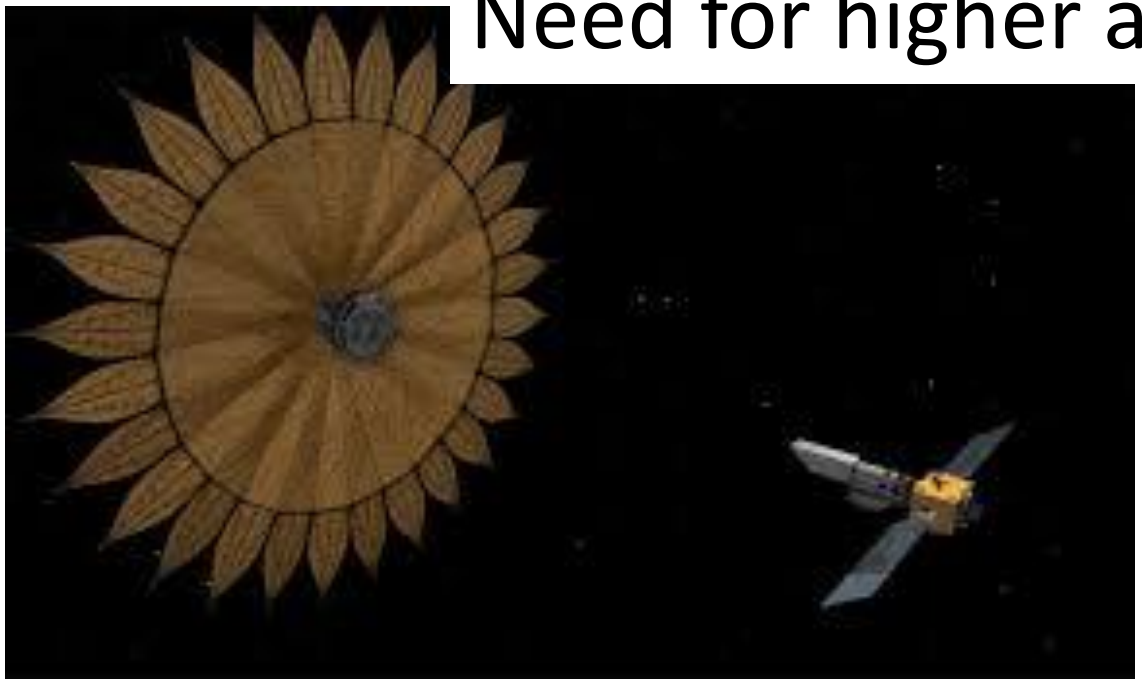
Aurora® FLIGHT SCIENCES



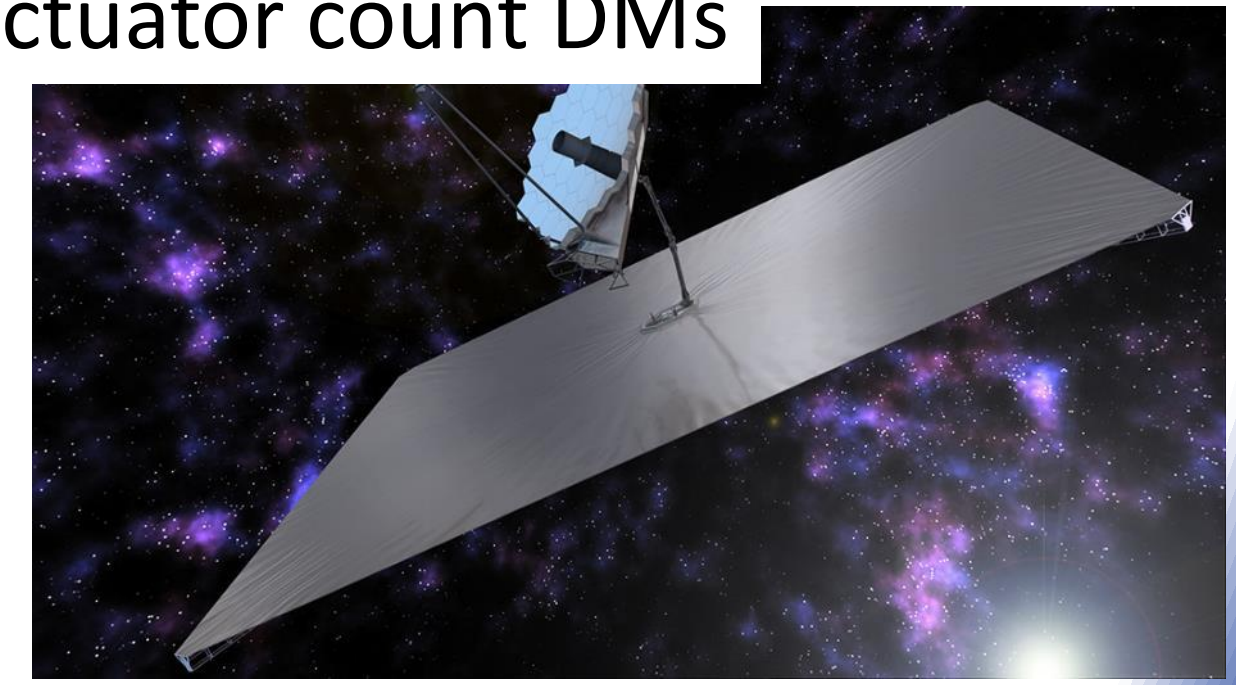
MIT STAR Lab

Future Space Missions

Need for higher actuator count DMs



Habitable Exoplanet Imaging Mission (HabEx)

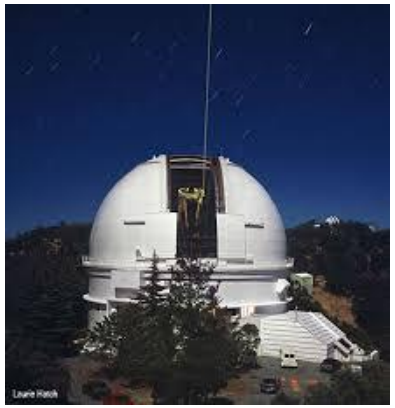


Large UV/Optical/IR Surveyor (LUVOIR)

Ground Based Astronomy with BMC Mirrors

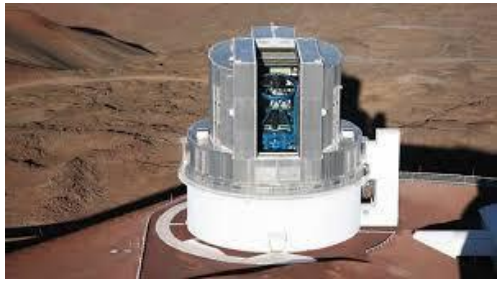
Kitt Peak 2,1m
Robo-AO

Lick Observatory
Shane-AO



Keck Telescope
Keck Planet Imager
and Characterizer

Subaru telescope
SCExAO



Gemini South
Gemini Planet

Magellan Telescope
MagAO-X

UH 2.2-m telescope
Robo-AO 2

Conclusion

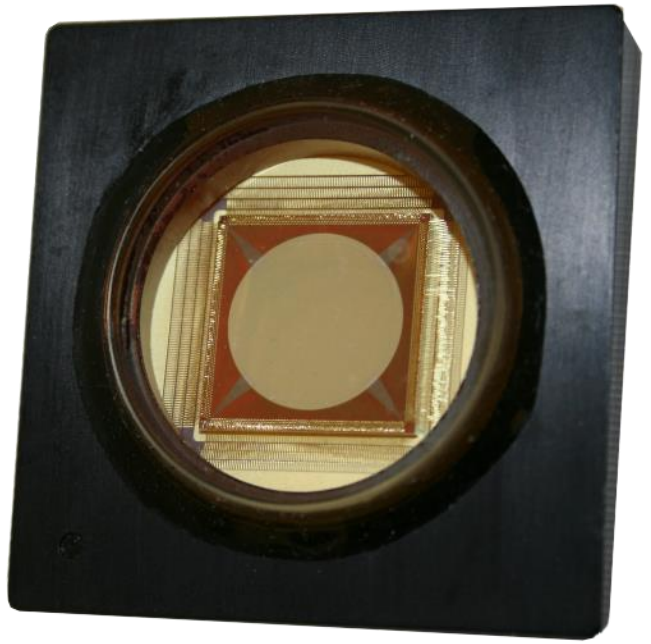
- TDEM program is progressing with conclusion early 2019
- Phase II-X program continued for WFIRST deliverable
- Results from our Phase I and II program show good promise for next generation MEMS DMs.

Acknowledgements

- Funding from NASA
  - **Contract#: NNH12CQ27C SAT/TDEM**
  - **Contract #: NNX16CP14C NASA Phase II SBIR**
  - **Contract#: NNX17CP76P NASA Phase II SBIR**
  - **Contract#: 80NSSC18P2056 Phase I SBIR**

Thank You

Questions?



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