



# ExEP HabEx MEMs DMs State of the Art and TRL

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# Boston Micromachines MEMs DMs

- Selected as baseline due to 400 um pitch, allows for more compact coronagraph design (saves mass, volume)
- ARC testbed electronics are more compact (lower mass, vol, pwr)
- Lower TRL than Xinetics, no environmental testing,  $2 \times 10^{-7}$  monochromatic

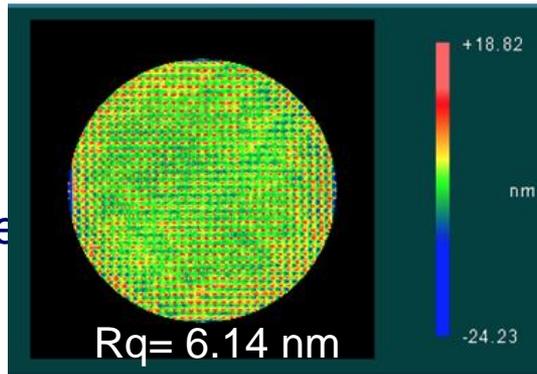
## Concerns

- Quilting: 3.3-7.6 nm RMS
- Scalloping: 12 nm PV
- WFE: ~6nm rms
- Self-correction uses stroke
- 100% actuator yield

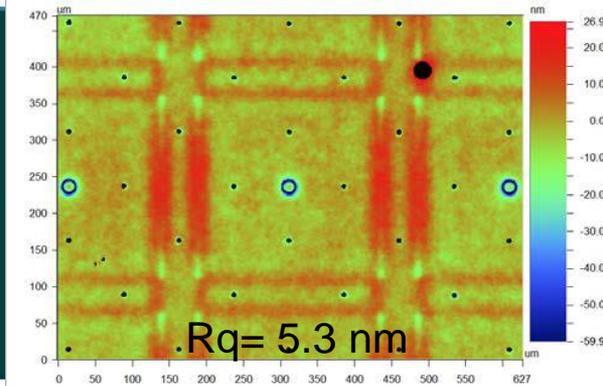
## Challenges

- Scaling to 96x96 requires new connectorization, has Phase1 SBIR *could raise current TRL 2 to 3*
  - >96x96 not possible with current BMC die size.
- Phase2 SBIR 2048 actuator to be more robust and have better WFE

Continuous DM Surface Data  
Powered Flat Image Circular Aperture  
(Tilt Removed)



Images courtesy Paul Bierden, BMC.





# Boston Micromachines in Use

- In Operation on Sky:
  - 140 actuator, ROBO-AO (Palomar 2012, Kitt Peak 2015)
  - 1024 actuator, Shane-AO (Lick Observatory 2013)
  - 2040 actuator, SCEXAO (Subaru 2013)
  - 4092 actuator, GPI (Gemini South 2013)
- PICTURE-B sounding rocket, 1024 actuators, 22.5 nm PV in flight, (2015)
- In Work:
  - MagAO-X (UofAz)
  - Rapid Transit Surveyor (UofH)
  - Keck Planet Imager and Characterizer (KPIC), 34x34 actuator
  - Caltech High Contrast Spectroscopy Testbed for Segmented Telescopes (HCST), 1000 segments = 3k actuators (Caltech)
  - Cubesat Demonstrator, 140 actuator, (MIT)
  - EXCEDE proposed for 2016 MidEx AO, demo'd of  $\sim 10^{-7}$  contrast 10% BW



# Deformable Mirrors

## Brief Description

Environment-tested, flight-qualified large-format deformable mirrors.

## Key Performance Capability Requirement

4 m primary:  $\geq 64 \times 64$  actuators  
Enable raw contrasts of  $\leq 1E-9$  at  $\sim 20\%$  bandwidth and IWA  $\leq 3 \lambda/D$ . Flight-qualified device and drive electronics (radiation hardened, environmentally tested, life-cycled including connectors and cables).

## Current State-of-the-Art

**Electrostrictive:** 64x64 DMs have been demonstrated to meet  $\leq 1E-9$  contrasts and  $< 1E-10$  stability in a vacuum environment and 10% bandwidth with a clear aperture; 48x48 DM passed random vibrate testing.

Drive electronics are large volume and mass.

**MEMs:** 64x64 DM in operation on GPI, 50x50 on SCExAO.

34 actuators diameter DM  $2 \times 10^{-7}$  over  $6-11 \lambda/D$   
Monochromatic (SPC open air);  $\sim 6$  nm RMS WFE flattened, 7.5 nm RMS quilting.

TDEM to environmentally test is in progress

Compact drive electronics developed by ARC are low power, low mass, not rad hard design.

## TRL Assessment: 5 for systems with monolith primary mirror, 4 for segmented Rationale

SOA: Xinetics 64x64 is TRL 5 for WFIRST application, and has been used in a lab to achieve the required HabEx/LUVOIR contrast with a clear aperture. Increasing the format size to a Xinetics 96x96 is a straightforward mosaicing.

MEMS DMs have enough actuator stroke for a segmented mirror but have never been used in a  $10^{-9}$  demonstration contrast.

Completion of TDEM environmental tests and demonstration of Enable raw contrasts of  $\leq 1E-9$  at  $\sim 20\%$  bandwidth in the DST could improve TRI to 5.