National Aeronautics and Space Administration

Early Stage Technology Workshop

Astrophysics and Heliophysics

March 3-4, 2015

MEMS Deformable Mirrors for Space Imaging Applications

4 March 2015

Boston Micromachines Corporation
Paul Bierden
President/CEO

TECHNOLOGY DRIVES EXPLORATION

Non-Proprietary

Boston Micromachines Corporation

- Founded May 1999
- Located Cambridge, MA
- Spin Out Technology from Boston University Photonics Center.
- **MEMS mirror products for beam control applications**
- Development of advanced optics and imaging systems
- Contract R&D (government and corporate)
- SBA Certified Small Business (13 FTE)
- Revenue
  40% Government Contract
  60% Product Sales

Select Customer List

NAOJ National Astronomical Observatory of Japan

Massachusetts Institute of Technology

l'Observatoire de Paris

THORLABS

MIT Lincoln Laboratory

Indiana University

University of Oxford

NASA

The University of Arizona Tucson Arizona

Imperial College London

Center for Visual Science

JAXA

Yale

Berkeley University of California

HHMI Howard Hughes Medical Institute

南京天文光学技术研究所 Nanjing Institute of Astronomical Optics & Technology NIAOT

ESO

The Schepens Eye Research Institute

National University of Ireland, Galway Ollscoil na hÉireann, Gaillimh

PSI Physical Sciences Inc.

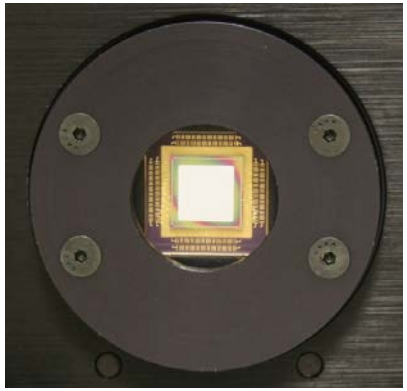
Harvard

Northrop Grumman

Lockheed Martin

Overview of Technology

- Optical MEMS, mainly deformable mirrors, for wavefront control in imaging applications
  - Modeling
  - Design
  - Layout
  - Manufacturing process definition
  - Packaging
  - Test
  - TRL 2-4 (maybe some at 6)



- Ongoing NASA Funded Projects
  - *Topography Improvements in MEMS DMs for High-contrast, High-resolution Imaging* NASA SBIR
  - *Enhanced Reliability MEMS Deformable Mirrors for Space Imaging Applications*, NASA SBIR
  - *MEMS Deformable Mirror Technology Development for Space-Based Exoplanet Detection*, TDEM

- Past Projects
  - SBIR/STTR/APRA Programs
    - Mirror development
    - Mirror improvement

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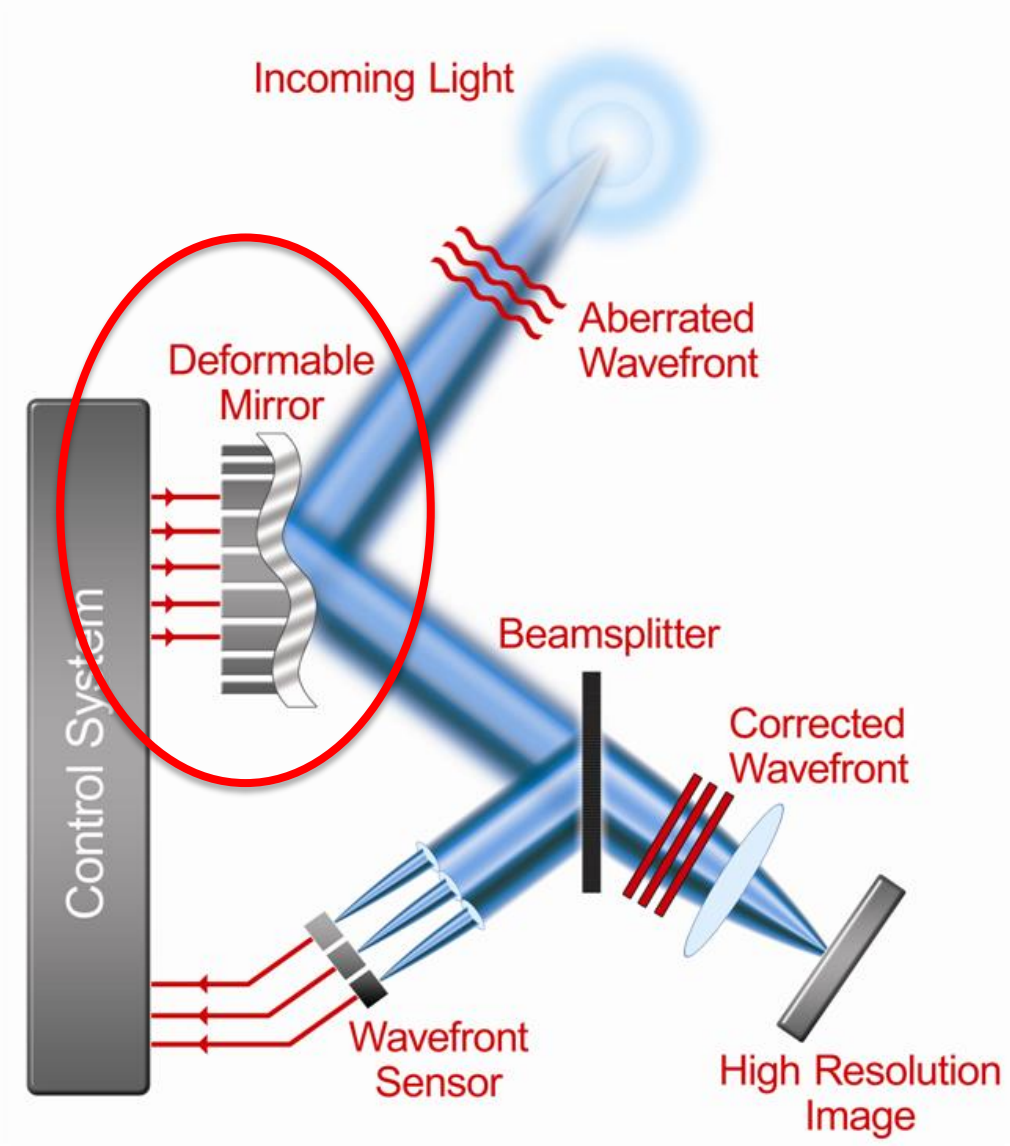
Adaptive Optics Overview



Aberrations are introduced from:
-Atmospheric turbulence
(ground astronomy)
-Thermal effects/optics tolerance
(space based astronomy)
-Tissue
(biological imaging)

Boston Micromachines makes deformable mirrors for all applications

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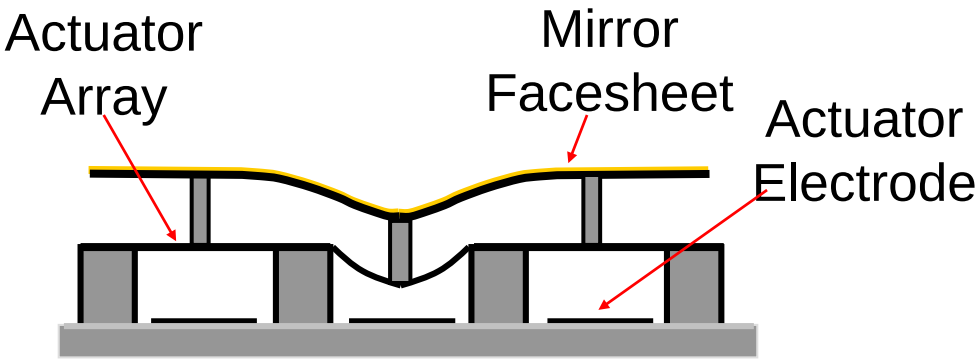
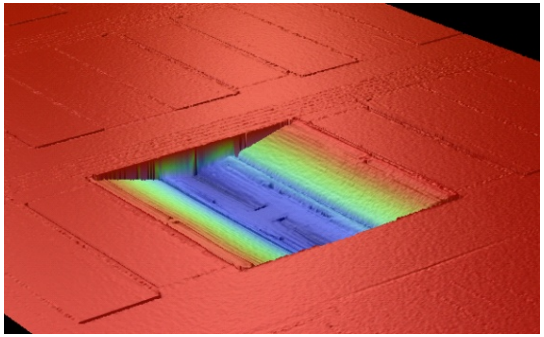
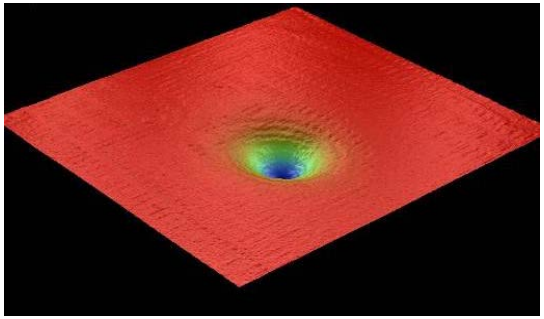
Silicon Surface Micromachined MEMS DMs



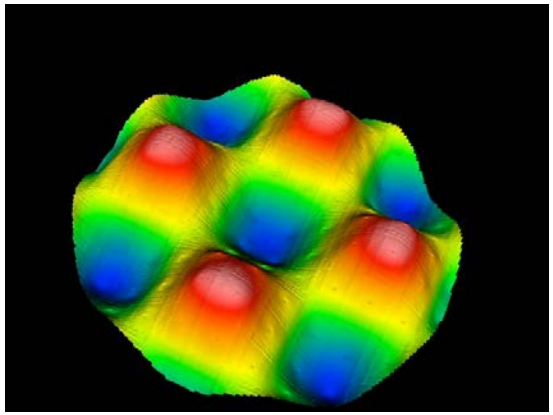


Deflected Actuator

Continuous mirror (smooth phase control)



Deformed Mirror Membrane



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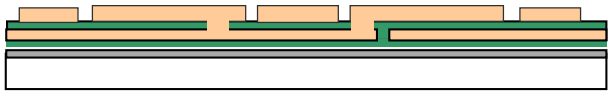
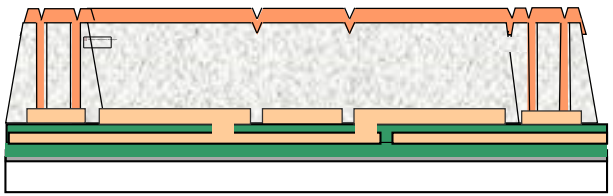
MEMS DM Fabrication

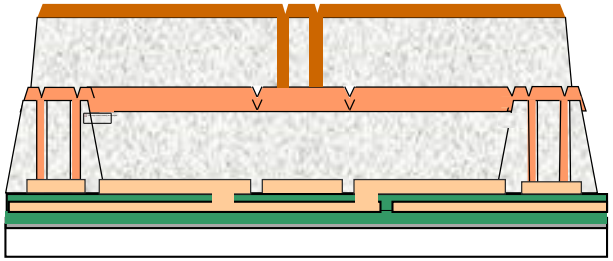
(deposit, pattern, etch, repeat)



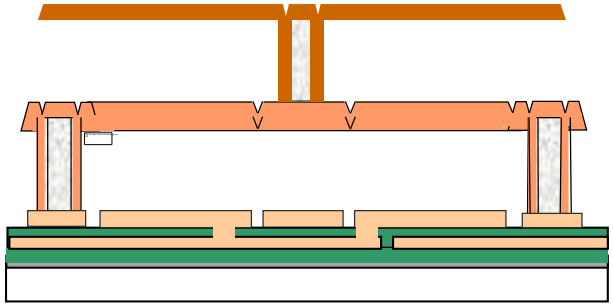
Electrodes & wire traces:
polysilicon (conductor) & silicon nitride (insulator)



Actuator array:
oxide (sacrificial spacer) and polysilicon (actuator structure)



Mirror membrane:
oxide (spacer) and polysilicon (mirror)

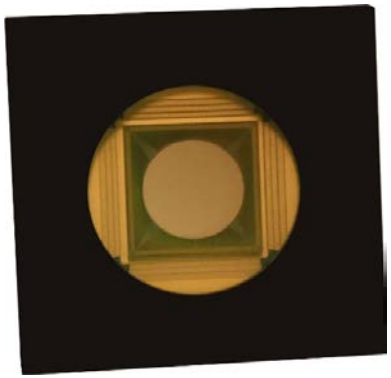


MEMS DM:
Etch away sacrificial oxides in HF, and deposit reflective coating

Attach die to a ceramic package and wirebond

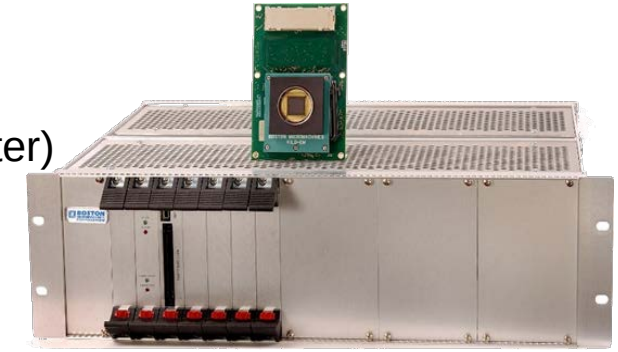
Non-Proprietary

BMC Astronomy DMs: Kilo-DM & 492-DM



Kilo-DM
- Square: 1020 actuators (32 x 32)
- or Circular: 952 actuators (34 across diameter)
- Continuous or segmented
- Stroke: 1.5 µm or 3.5µm

492-DM
- 492 actuators (24 across diameter)
- Continuous or segmented
- Strokes: 1.5µm or 3.5µm



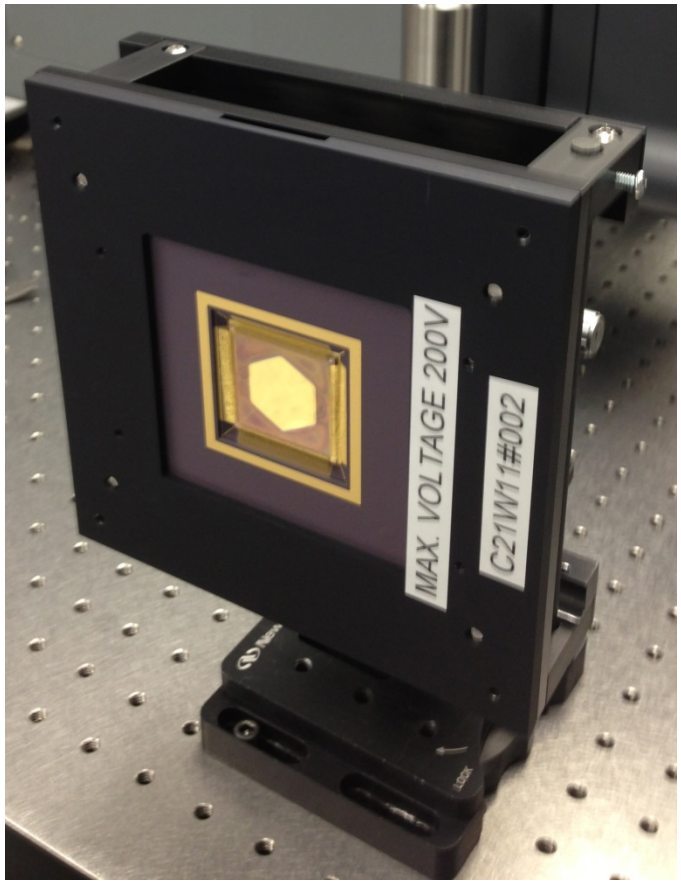
2k Continuous DM

- 2048 actuators
- 50 actuators across diameter
- 400um pitch
- 3.5µm stroke
- Full aperture unpowered figure
  - 86nm RMS
  - 570nm P-V

Non-Proprietary

Tip/Tilt/Piston DM

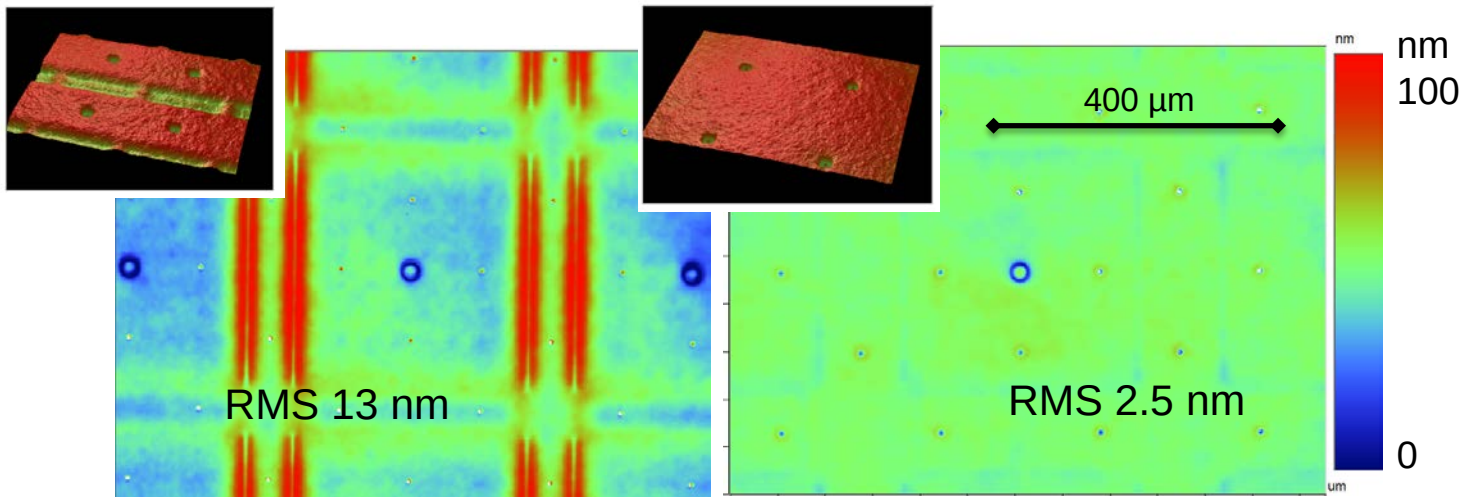
- 3063 actuators
- 1021 Mirror Segments
- 300um pitch
- 1.5µm stroke
- 0.5° Tip- Tilt
- Delivered to JPL 2013



Non-Proprietary

Ongoing NASA-sponsored research

- Topography improvements in MEMS DMs for high-contrast, high-resolution imaging
- New processing steps reduce “print-through”



BMC’s heritage process

BMC’s modified process

Contract#: NNX13CP03C

Why Topography Improvement

In high contrast imaging for exo-planet detection the presence of the diffraction peaks in the image plane creates optical problems:

- Local blind spots in the image plane
- Extended light leak from diffraction peaks across the image plane
- Chromaticity of the diffraction orders

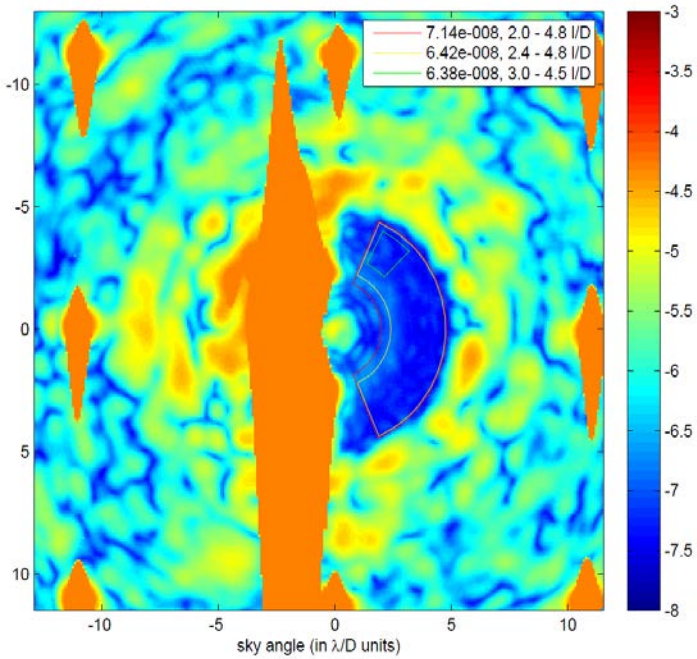
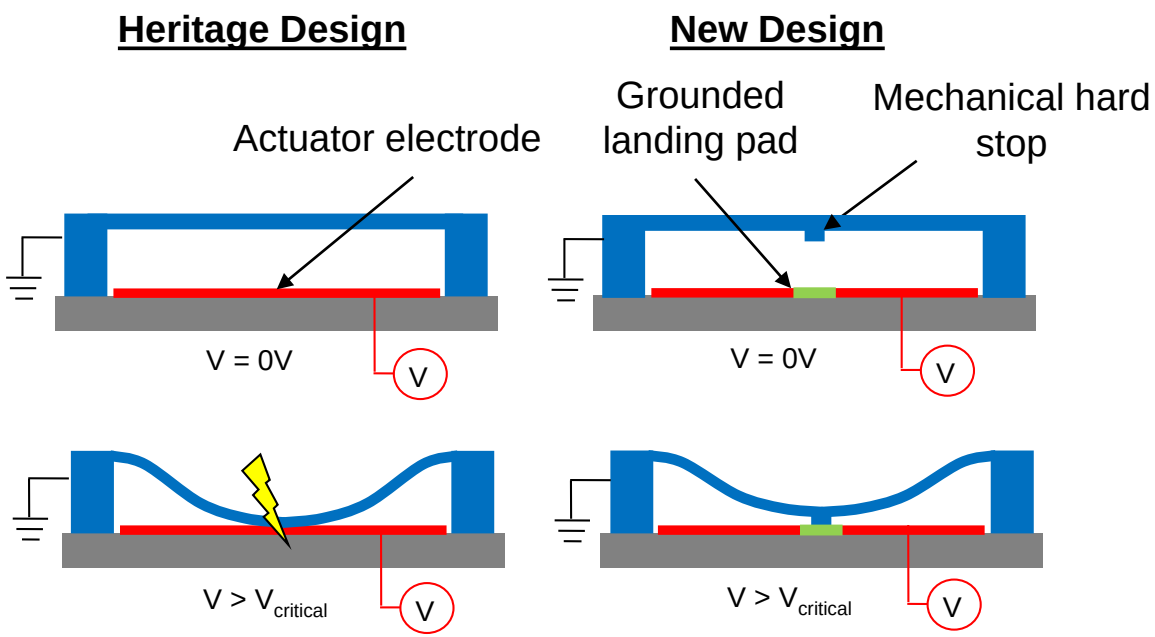


Image from R. Belikov, NASA AMES

Non-Proprietary

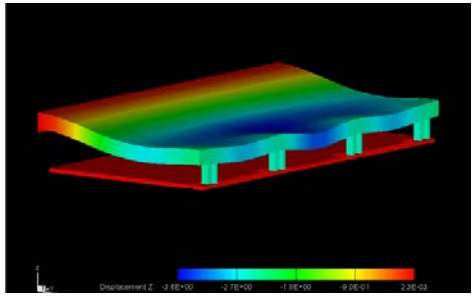
Ongoing NASA-sponsored research

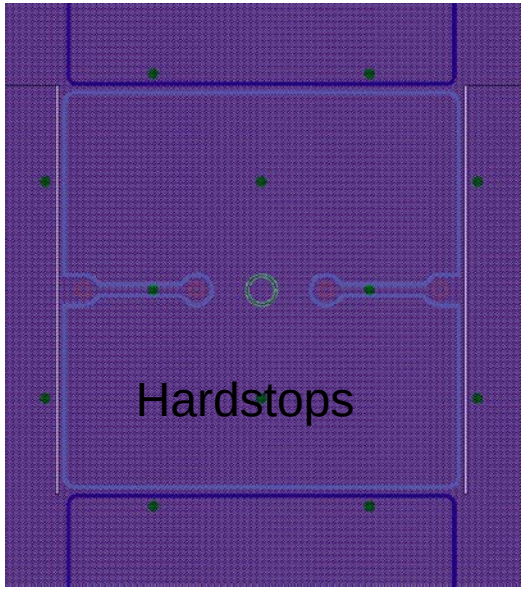
Enhanced reliability MEMS DMs for space-based applications

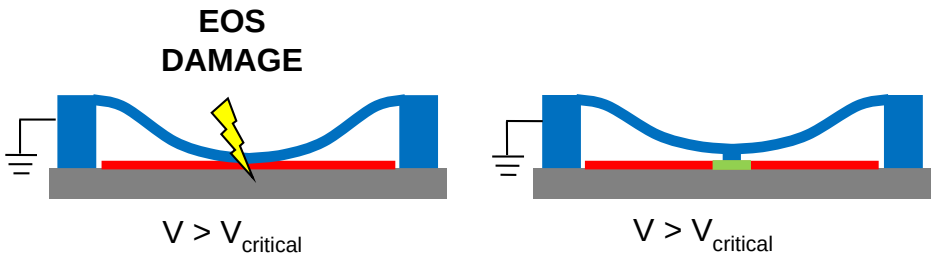


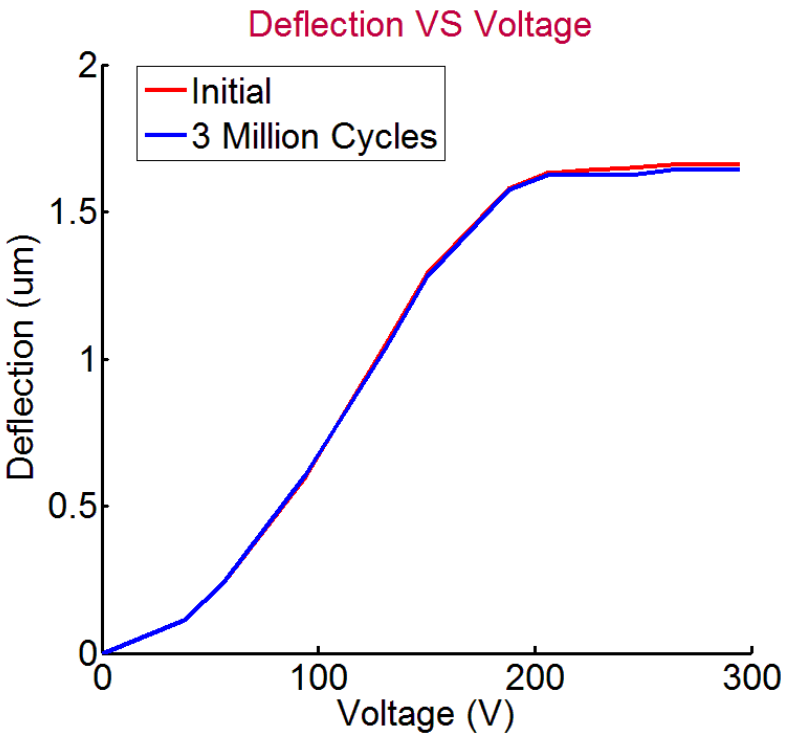
Reliability with Hard Stops

Enhanced Reliability
Actuator Design









Deflection versus voltage. Initial, after cycling 3 million times above critical voltage (295V).

Ongoing NASA-sponsored research

NASA environmental testing

Vibration

Acoustic sonification

Shock

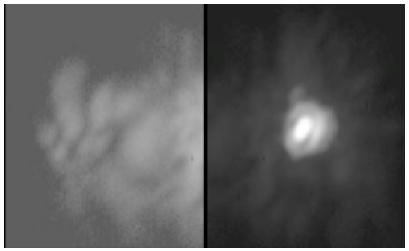
Goal : Increase TRL by testing in flight like conditions

Observatories w/ BMC DMs on sky

- Lick Observatory (VILLaGEs):

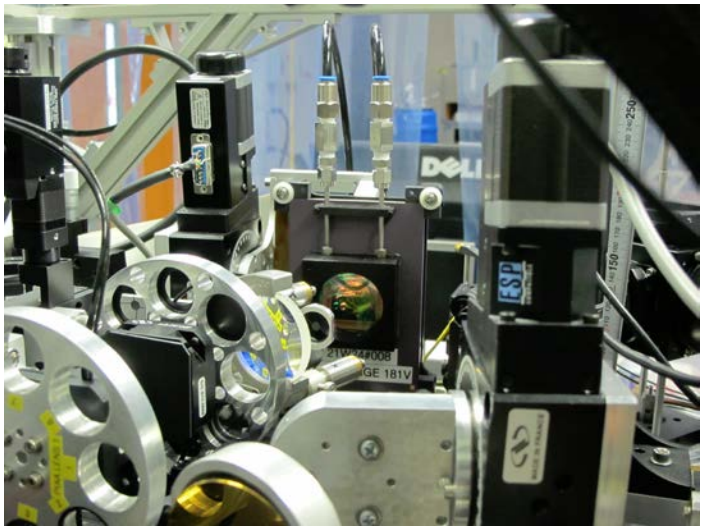
  Multi DM, visible AO on 1m telescope (2007)

  Kilo DM, visible AO using on 3m telescope (on-sky 2012)
- Palomar Observatory (Robo-AO): Low-cost, autonomous, integrated laser adaptive optics system, **Multi DM** (2011)
- Table Mountain Observatory (TMO) and A Pomona Adaptive Optics (KAPAO): Natural guide star adaptive optics system, **Multi-DM**

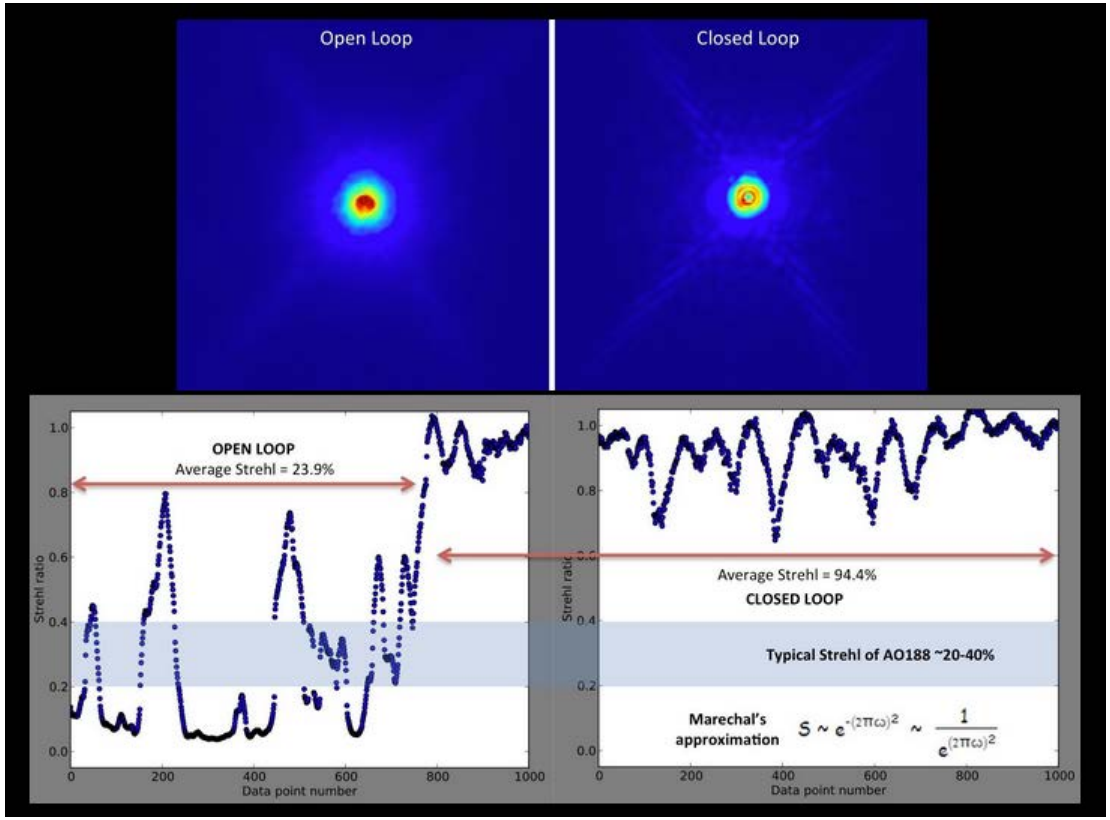


Gavel D, et al. SPIE, 2008:688804-7.

Subaru Telescope Extreme Adaptive Optics



2K Mirror in coronagraph



Results showing improvement in Strehl from 23.9% - 94.4%

Gemini Planet Imager

The Gemini Planet Imager's main component is BMC's 4092 actuator DM with 3.5µm stroke, for Jovian exoplanet detection.

- Deployed on the 8-meter Gemini South Telescope
- first light image of the light scattered by a disk of dust orbiting November 2013

Beta Pictoris

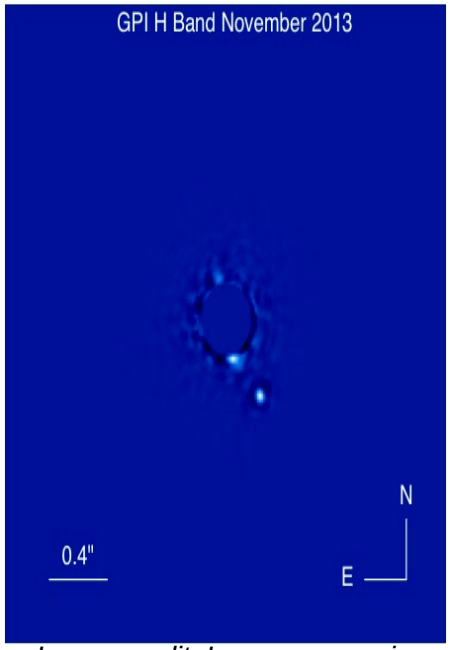


Image credit: Image processing by Christian Marois, NRC Canada

young star HR4796A

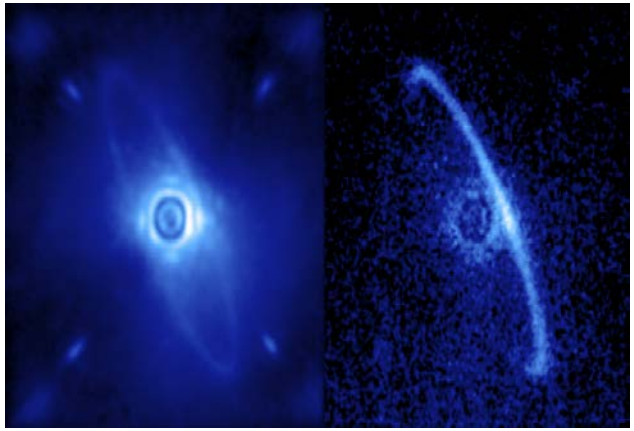
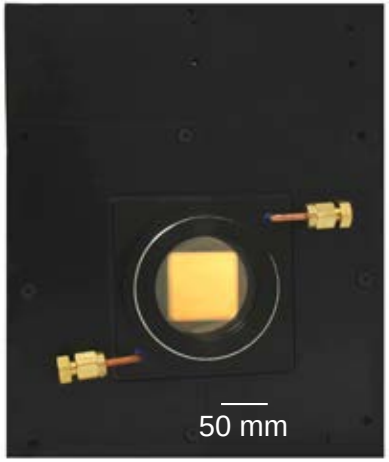


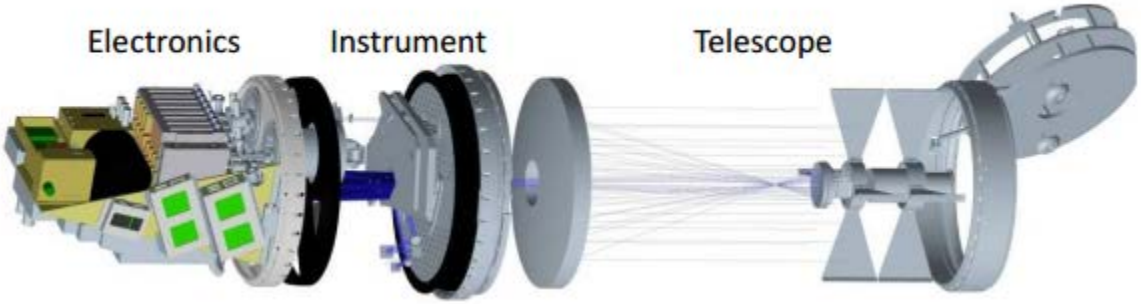
Image credit: Processing by Marshall Perrin, Space Telescope Science Institute



PICTURE

Planetary **I**maging **C**oncept **T**estbed **U**sing a **R**ocket **E**xperiment

Sounding Rocket



TRL 6?

Non-Proprietary

Testbed for Next Generation Astronomical Instruments

AMES RESEARCH CENTER

NASA

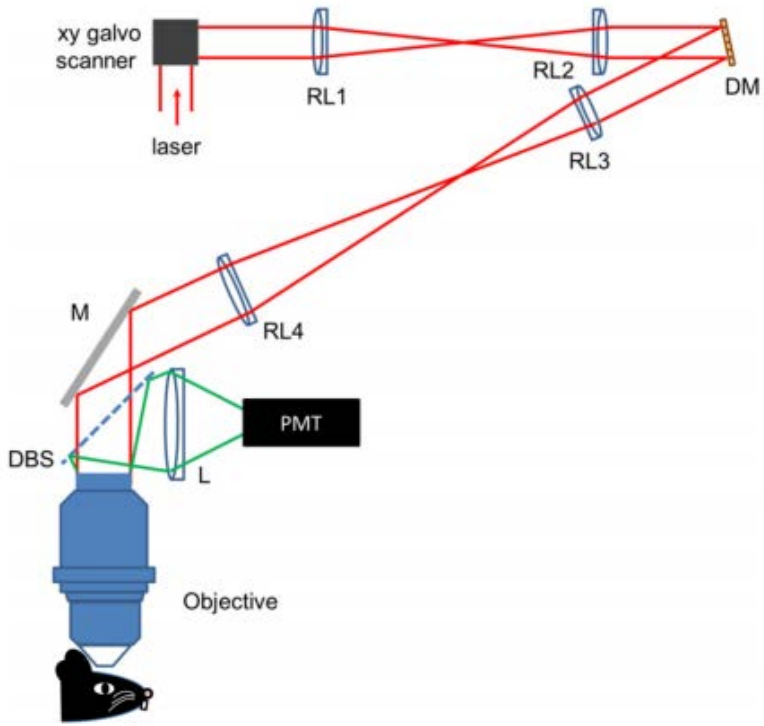
SPACE TELESCOPE SCIENCE INSTITUTE

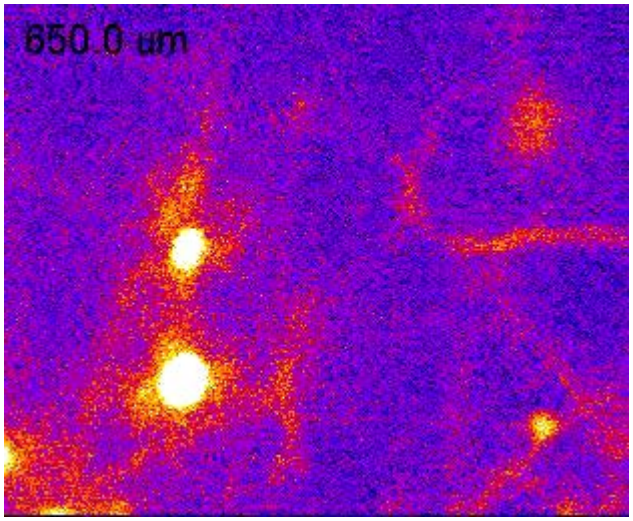
l'Observatoire de Paris

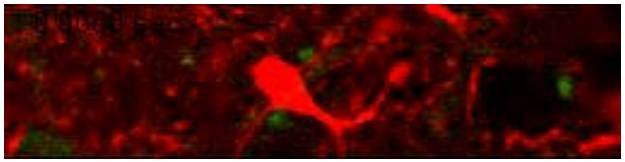
Observatoire de la CÔTE d'AZUR

Super Penetration MPM

- New work released by M. Cui of Janelia Farms,HHMI
- *In vivo* imaging of functional mouse brain through the skull



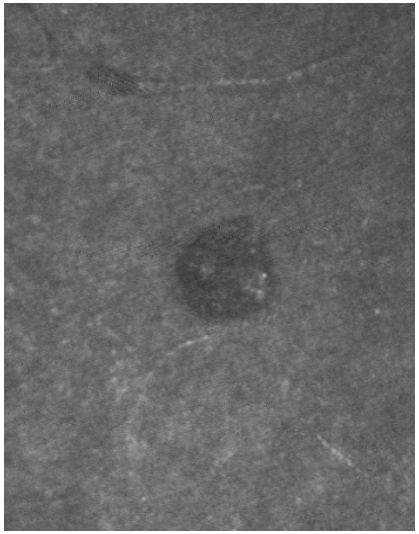


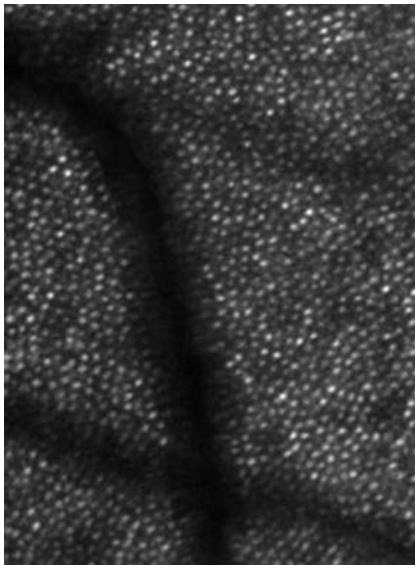


Non-Proprietary

AOSLO
Adaptive Optics Scanning Laser Ophthalmoscope

- A technique used for *in vivo* imaging in the human retina
- Utilizes adaptive optics to remove optical aberrations from images obtained from scanning laser ophthalmoscopy of the retina
- Obtains cellular level resolution images





Why is MEMS DM Development Important

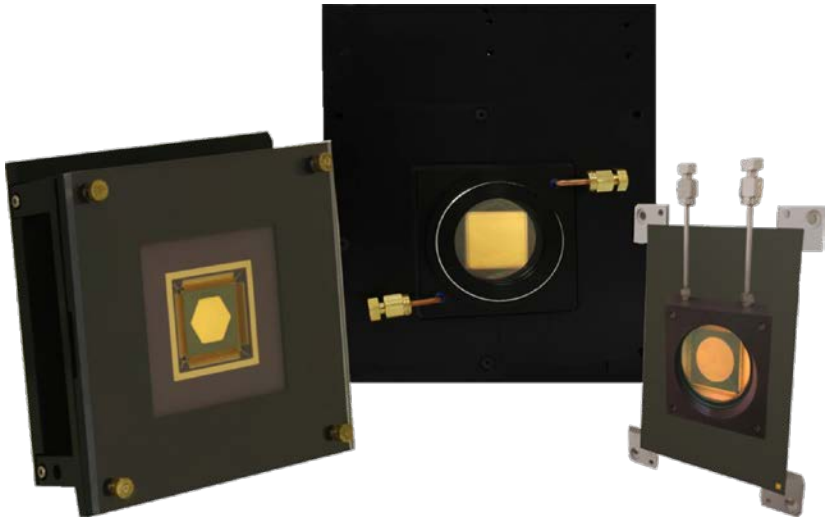
- The Decadal Survey of Astronomy and Astrophysics 2012-2021:
  - #2 “seeking nearby habitable planets”
  - High Contrast imaging/Exoplanet detection needs new DMs
- Extremely Large Telescopes
  - Need AO
  - Need Deformable Mirror Technology
- White House BRAIN Initiative (**B**rain **R**esearch through **A**dvancing **I**nnovative **N**eurotechnologies)
  - Demonstrated new capabilities with MEMS mirrors

Summary

BMC has core strengths in design, manufacturing, testing, packaging and integration of advanced micromirror systems.

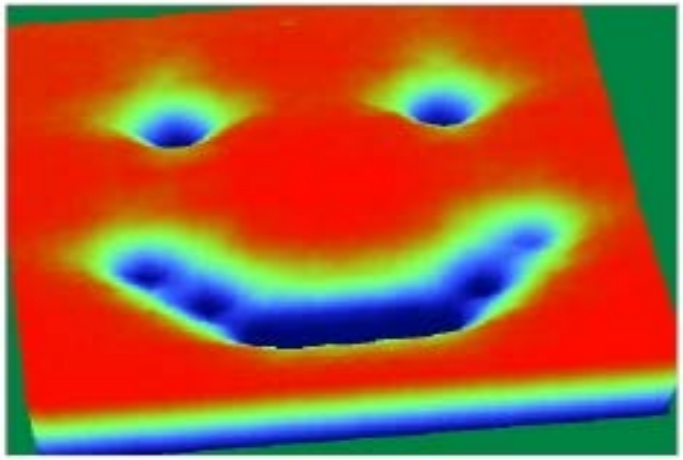
BMC has provided and continues to innovate deformable mirror technology for NASA's exoplanet missions.

BMC is committed to advancing technology for optical systems in a variety of markets, providing components, sub-systems and instrumentation.



Thank you!

Questions?



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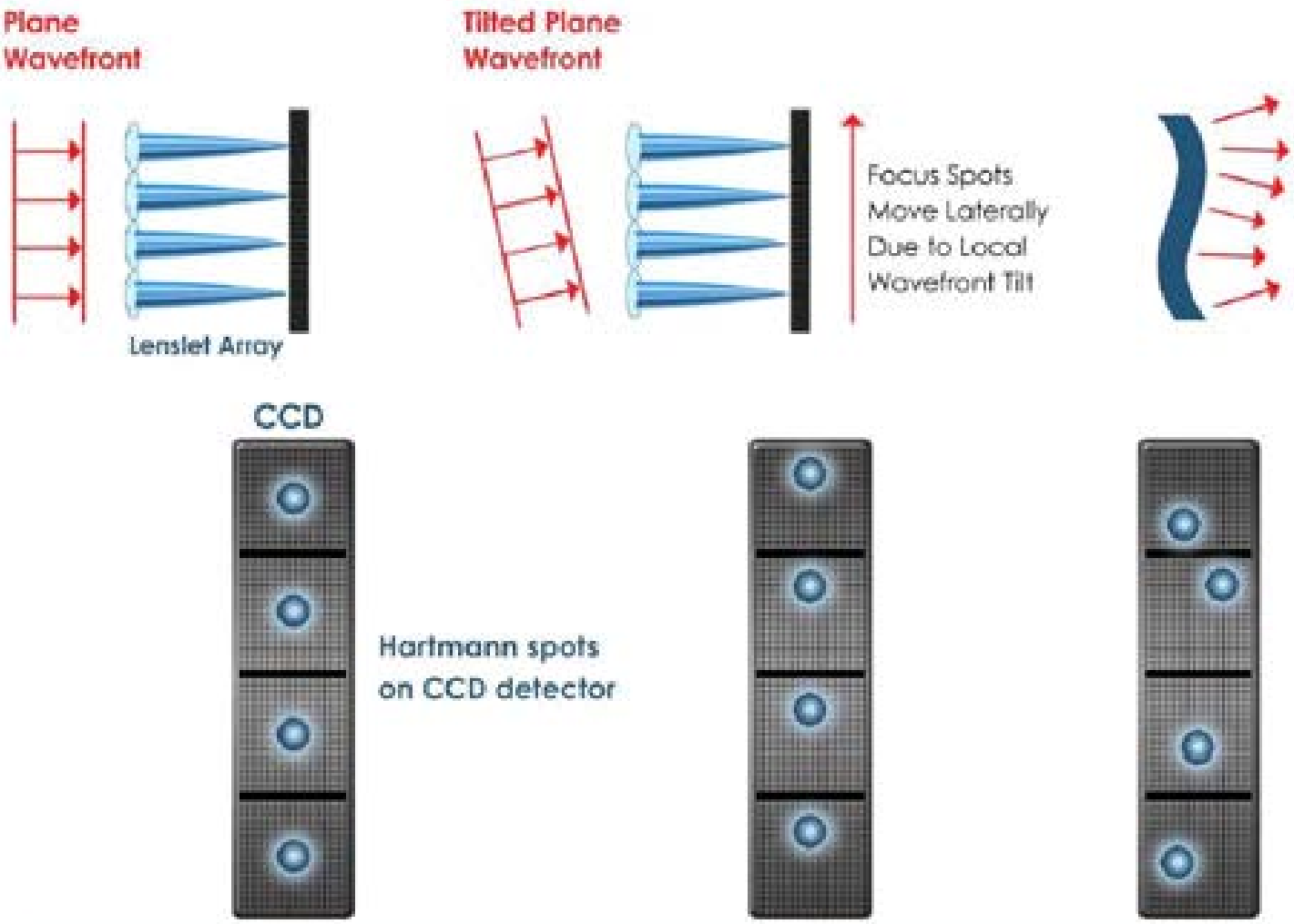
Back-up charts

BMC DM Products

Product Name	Number of Actuators across aperture	Total Number of Actuators
MINI	6	32
MULTI	12	140
C-MULTI	13	137
492	24	492
KILO	32	1020
C-KILO	34	952
2K	48	2040
3K	62	3064
331 TTP	~30	993
1021 TTP	~60	3063
Linear Array	140	140

Shack Hartmann WFS