Extreme-Precision MEMS Segmented Deformable Mirror (NASA Phase II SBIR)

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NASA Mirror Technology Days

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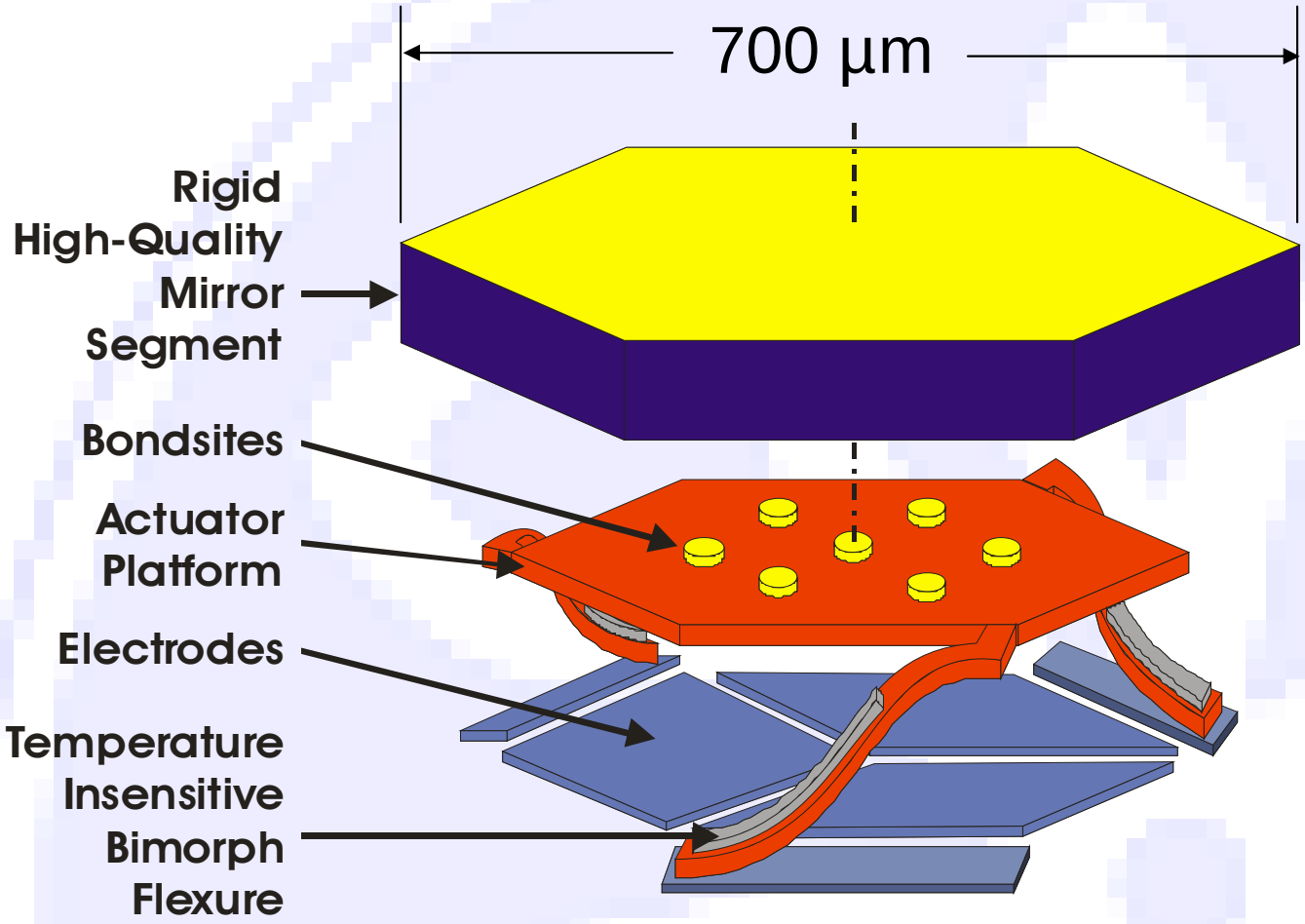
Iris AO Introduction

- Founded in 2002
- Based in Berkeley, CA
- Small high-technology firm specializing in MEMS AO
  - High-performance, robust MEMS based DMs that address a large application space
  - Multi-channel high-voltage drive electronics
  - AO imaging systems

Segmented MEMS DM Schematic



- Robust assembled mirror surface stays flat (0.56 nm/°C PV)
- Temperature-insensitive bimorphs elevate mirror above substrate (14 nm/°C, σ=0.8 nm/°C)
- Piston/tip/tilt electrostatic actuation

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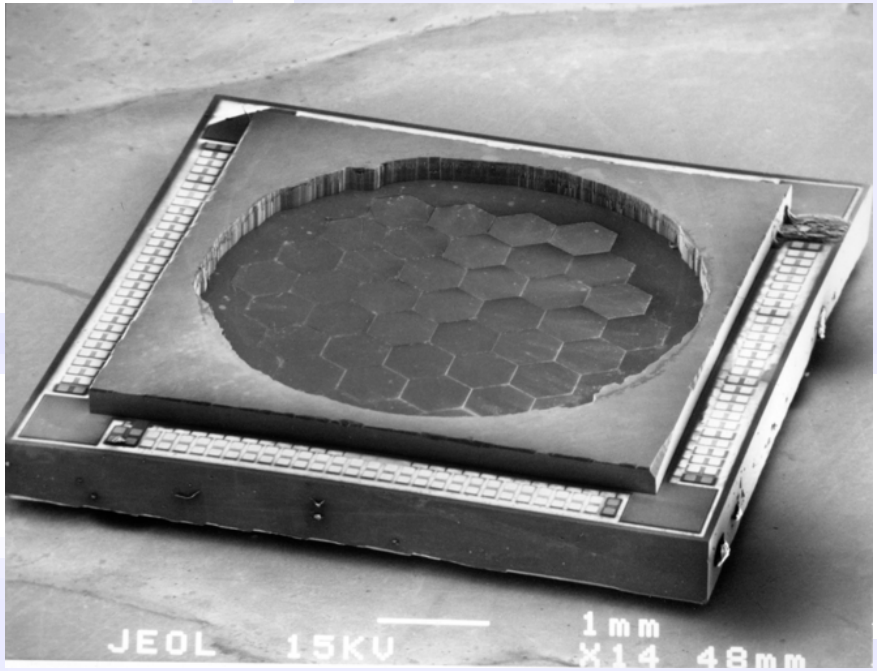
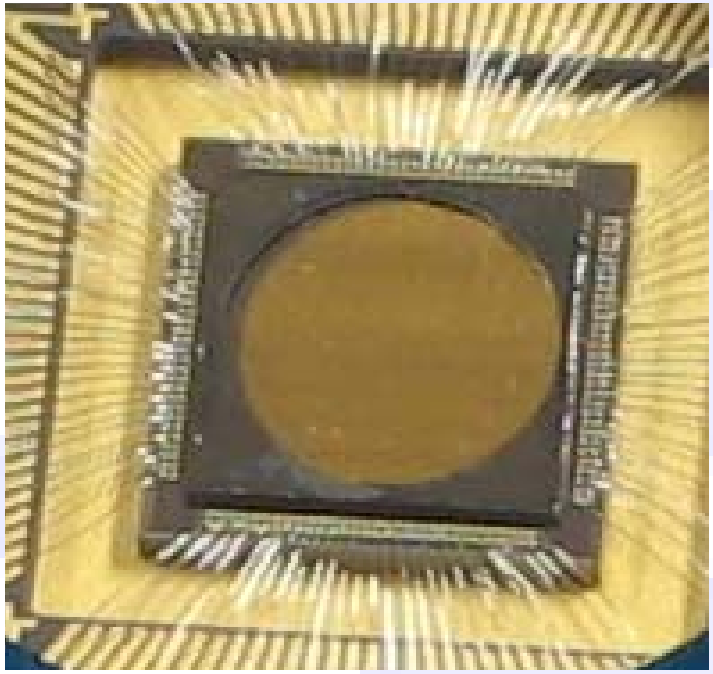
37-Segment PTT DM Images





3.5 mm inscribed aperture

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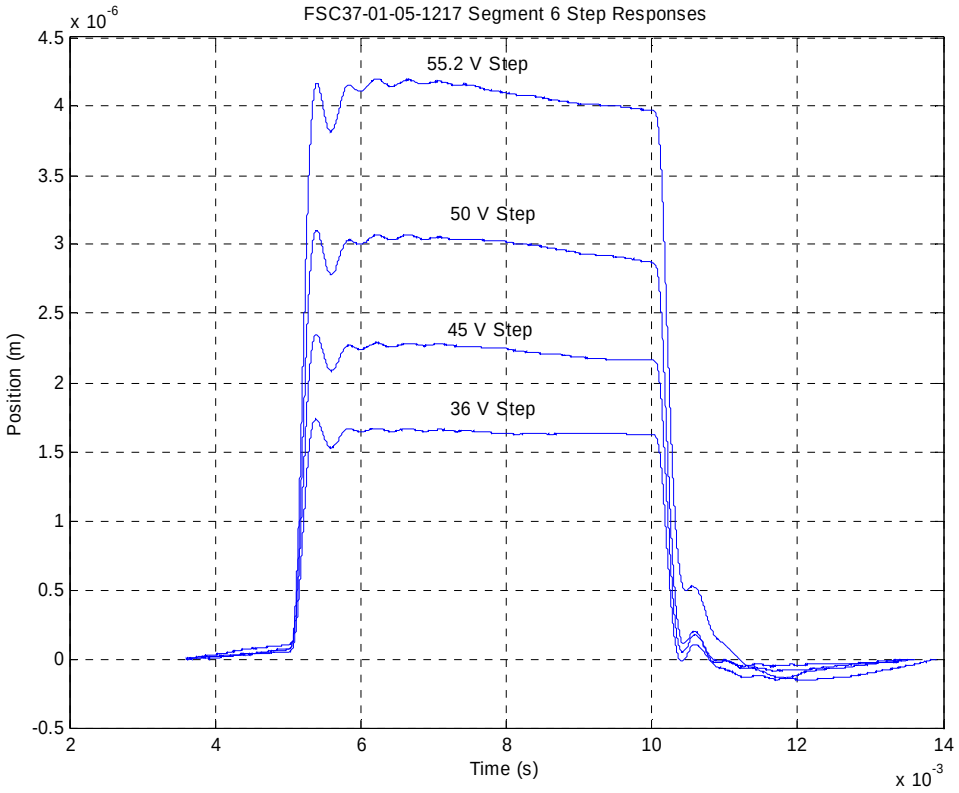
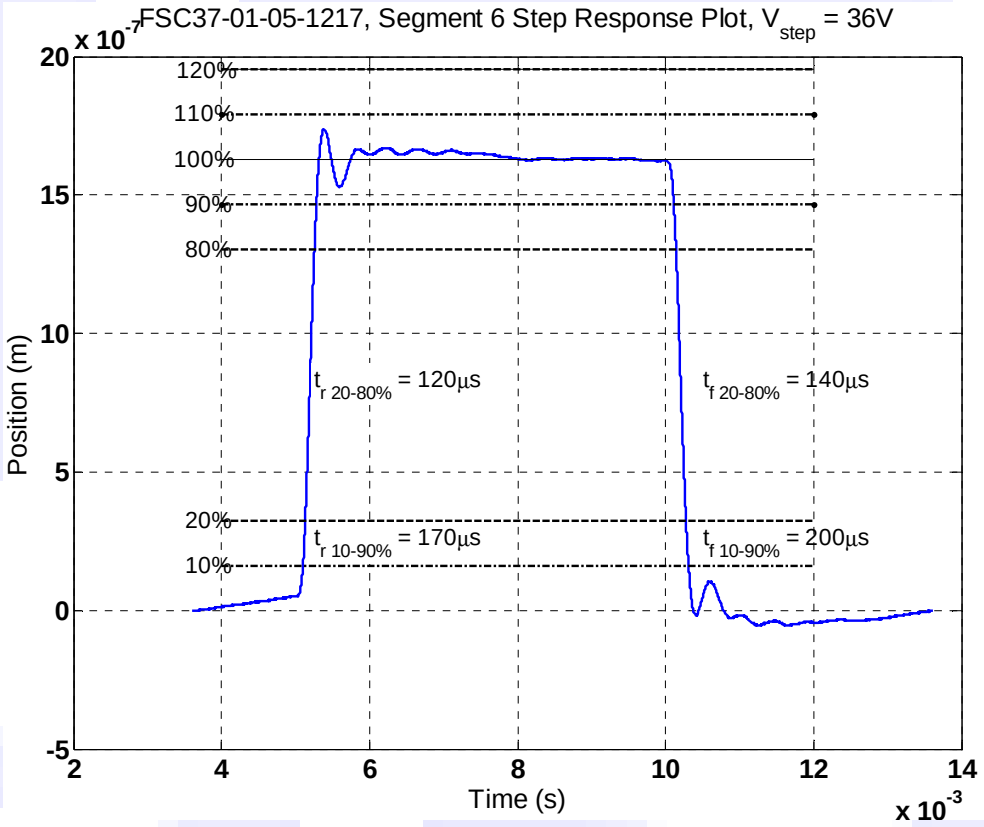
Step Response





120/140 µs rise/fall times, 20-80%; 1.63 µm, 36 V
DMs can survive ~350 G shock/vibration unpowered

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Phase II SBIR Goals

Performance Period: Jan 29 2007 – Jan 28, 2009

Specification	Current DMs	Phase II Demo Goal*	Phase II Study Goal
Surface Figure Errors (nm *rms*)	6-20	1-3	0.1
Positioning resolution *(*nm *rms)*	5 (elect noise limited)	0.14	0.04
Open-loop positioning accuracy *(rms)*	20-30 nm	10 nm	Not Specified
Stability *(*nm *rms)* • over 15-60 min	0.2-1.2 (5 elect. noise)	0.2	0.04
Failure Testing: Continue testing and determine techniques to eliminate potential snap-in failures			

*** Independent verification by the Lab for AO at UC Santa Cruz**

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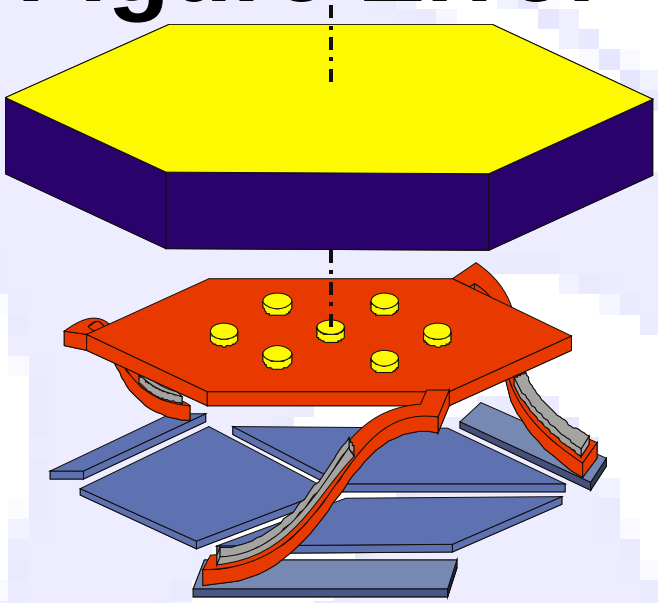
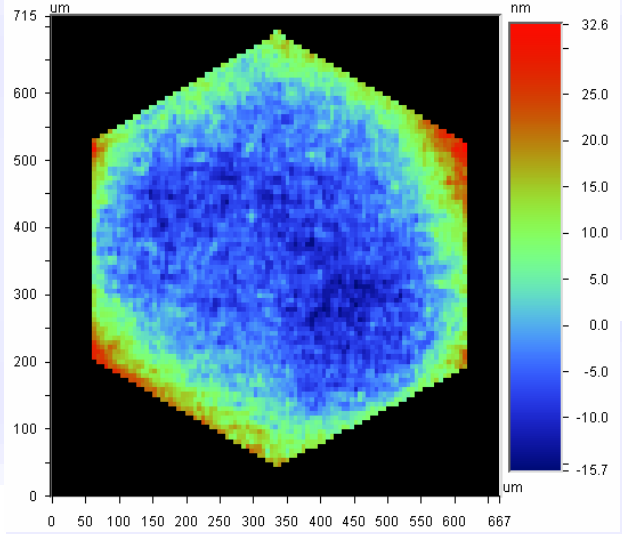
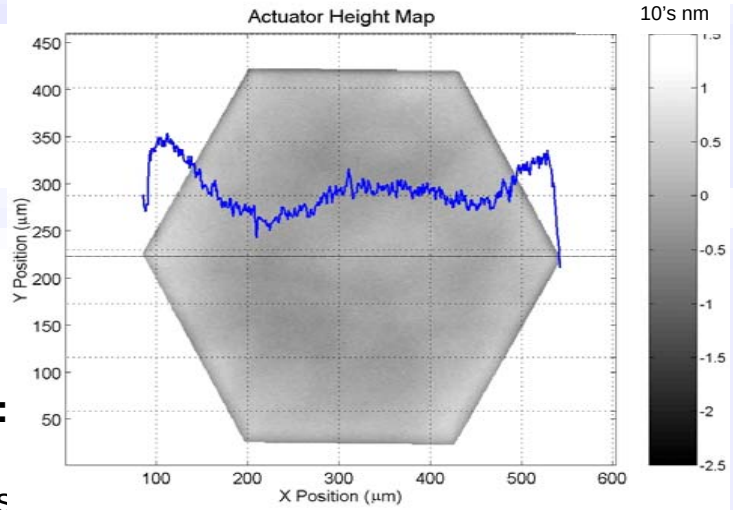
Surface Figure Error

- **Current designs: 6-20 nm *rms***
  - **Single-crystal silicon segments**
  - **Segment thickness = 20 µm**
- **Thicker ➡ Flatter**
  - **Surface figure errors $\propto 1/t^{2\text{-}3}$**
  - **DMs with 25 and 30 µm nearly complete**
    - **1.6-2X/2.3-3.4X improvement**
  - **50 µm mirror wafers damaged in processing**





700 µm Segment:
Rq = 7.8 nm *rms*



500 µm Segment:
Rq = 2.1 nm *rms*

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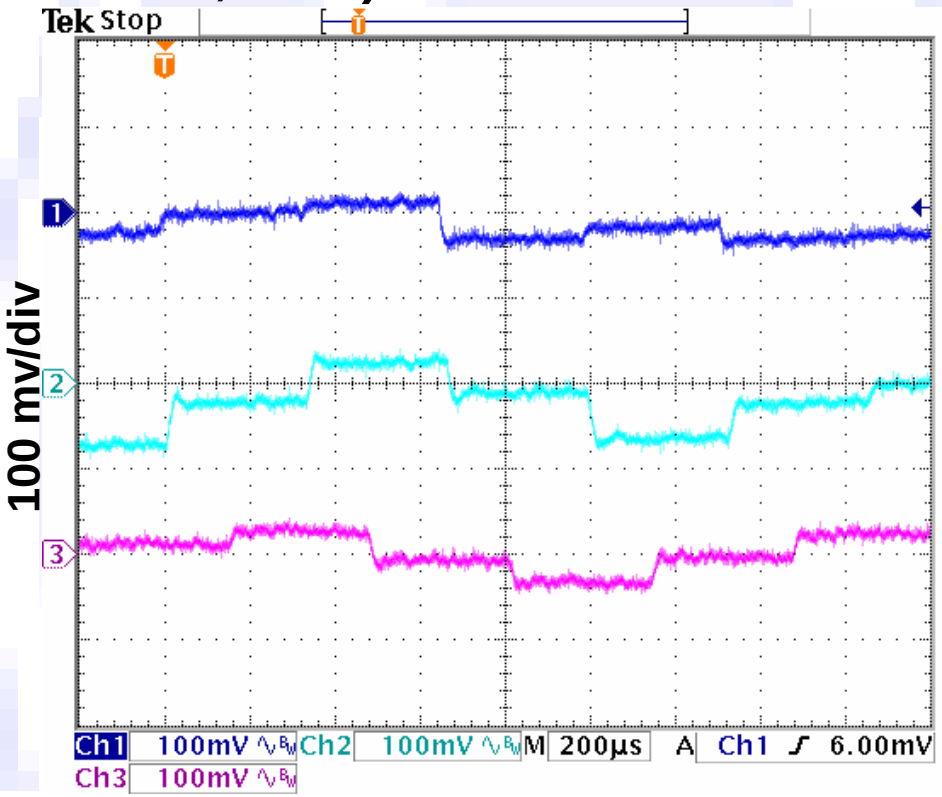
Extreme-Positioning Resolution

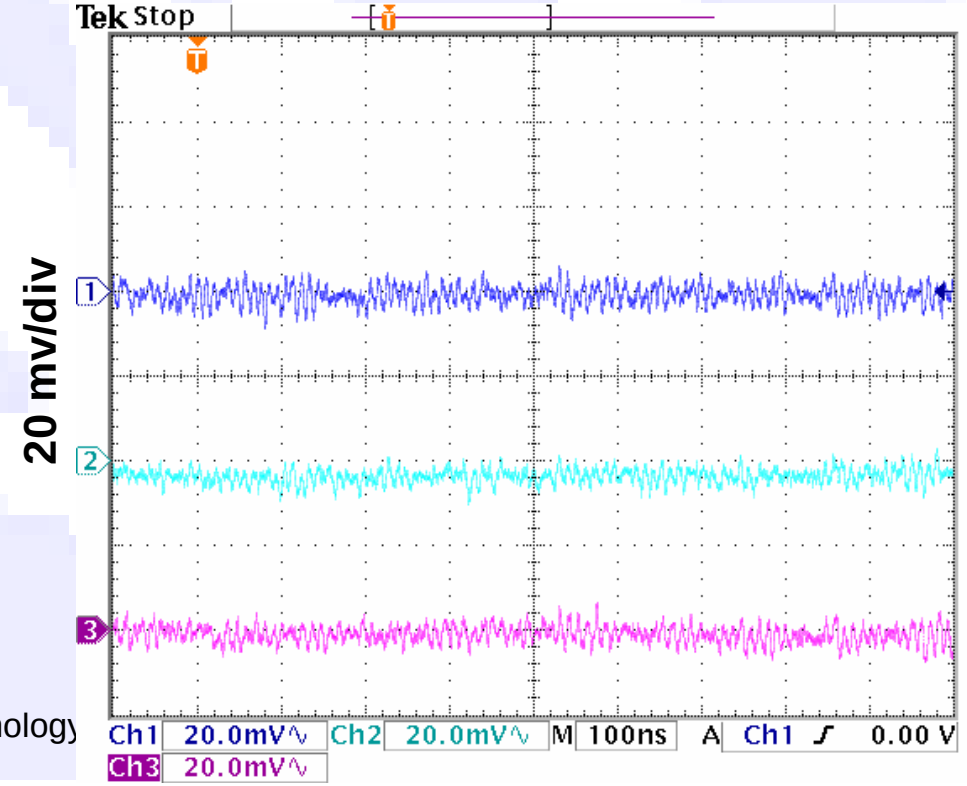
Smart Driver Electronics

- 50 mV *rms* SH refresh noise
- 3.2khz (SH DAC update rate)
- ~ 5 nm *rms* position noise (current DM design)
- Quantization noise: 2.5 mV (14.5 bits, 200V)



Smart Driver II Elect. Breadboard

- 3.3 mV rms electrical noise
- High frequency
- 0.3 nm *rms* position noise (current DM design)
- Quantization noise: 3.5 mV (14 bits, 200V)



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Smart Driver II Electronics

Smart Driver II Specifications

- **14 bit**
- **200 V**
- **Compact version: 128 channels**
- **2U 19” rack mount: 512 channels/box**
- **(Low speed) USB scales to 64k channels (128 x 512 channels)**
- **High speed interface will scale to >4k channels/interface**
  - **Preliminary planning stage**

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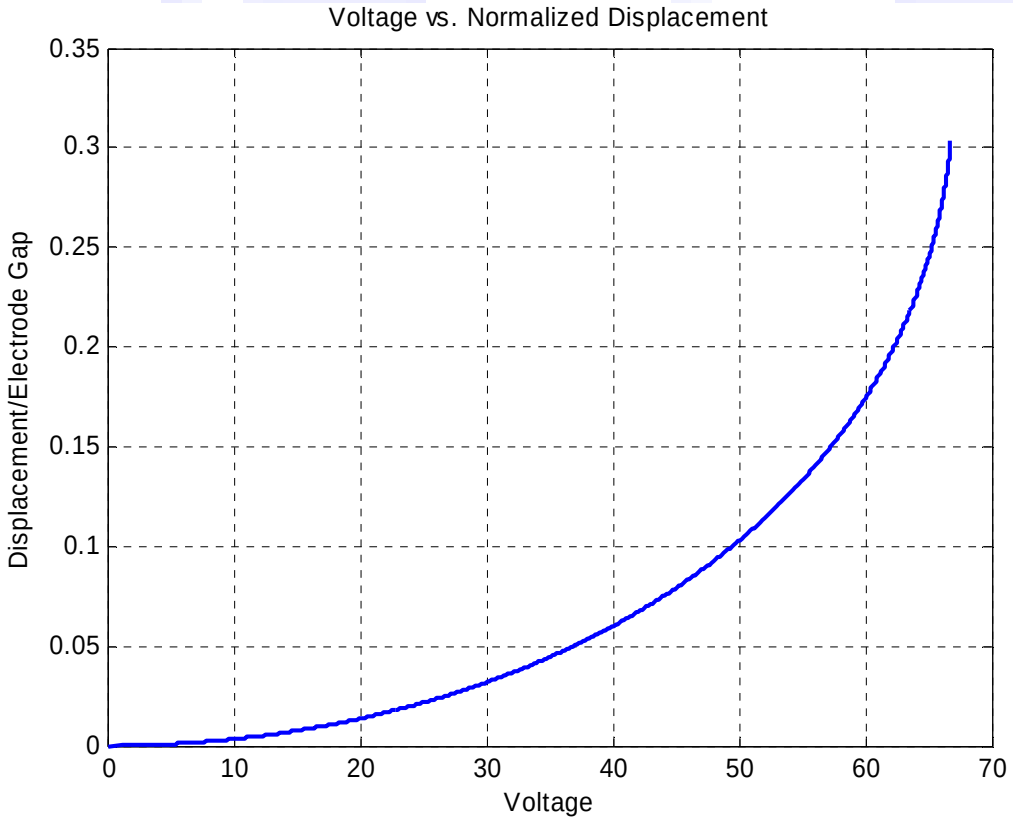
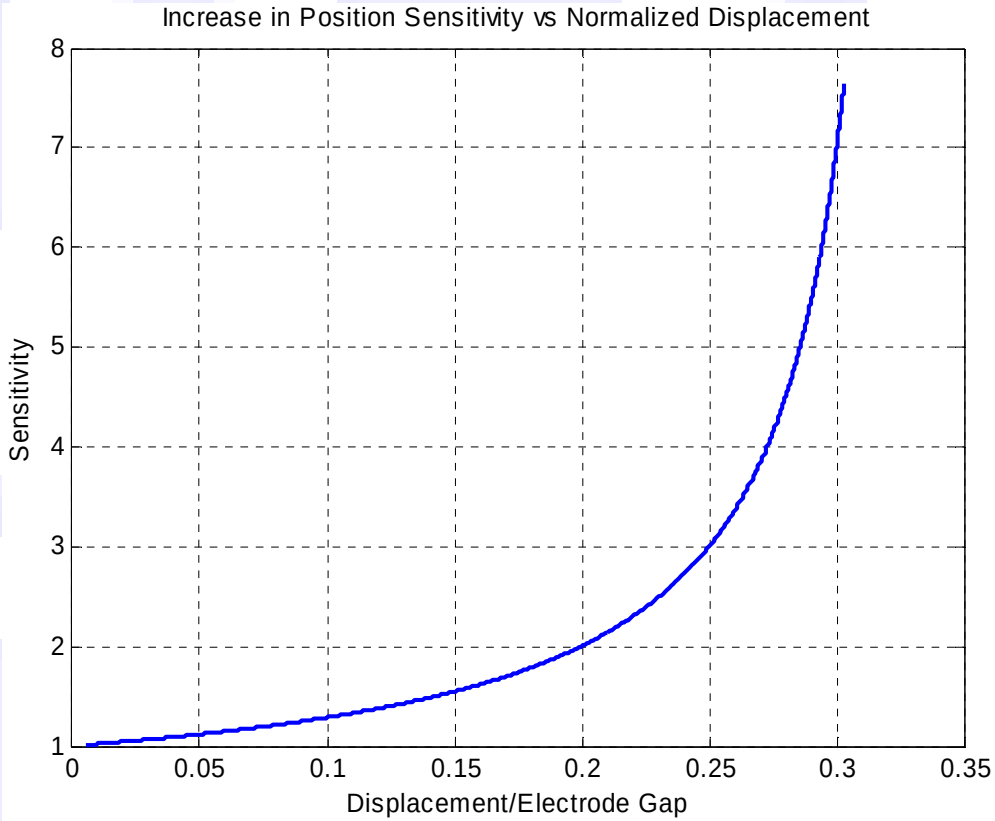
Extreme-Positioning Resolution Limits

- **Current S37-5 DM uses only 1/3rd of the Smart Driver dynamic range**
- **Redesign DM to use all dynamic range**
- **Use more linear region**

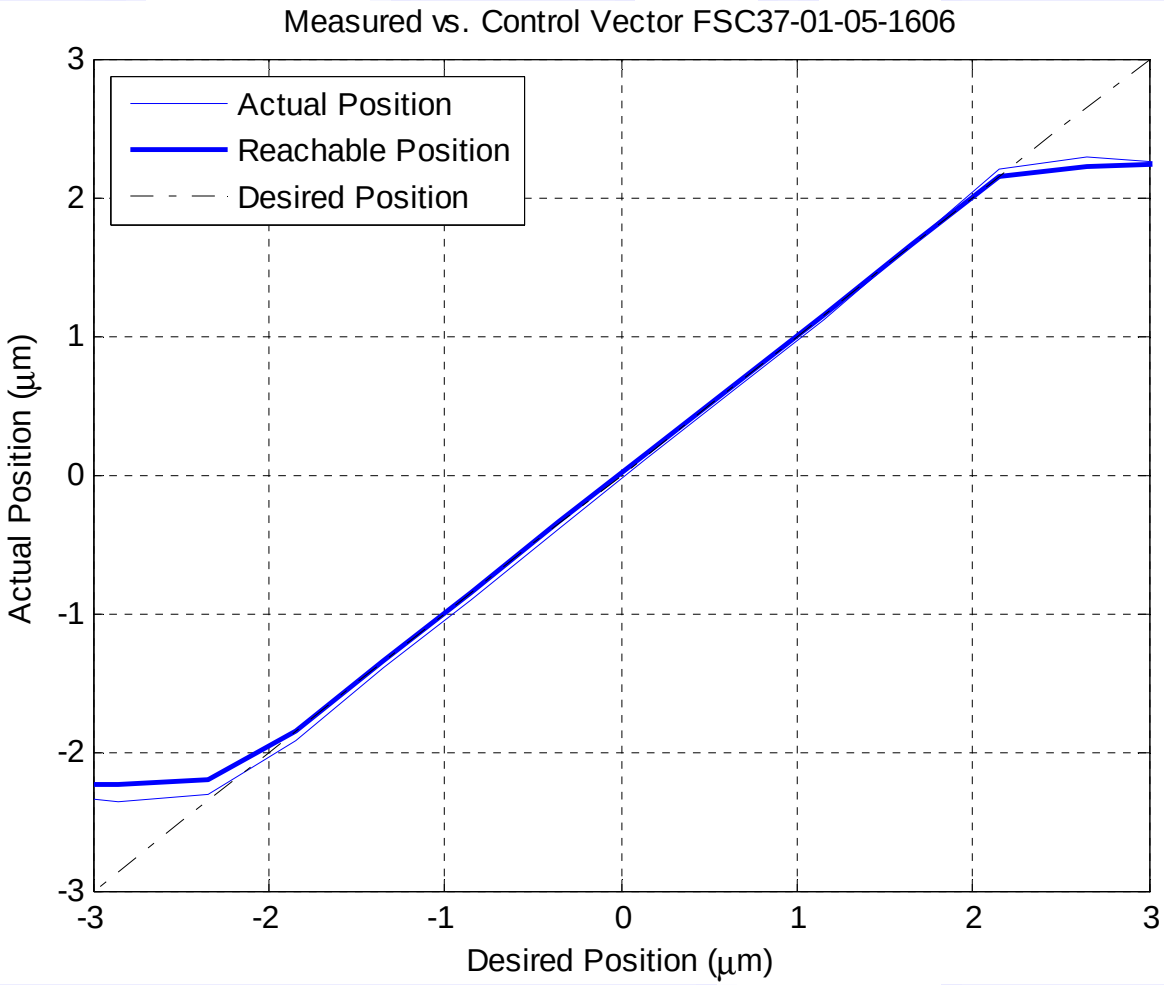
  ➡ 0.14 nm *rms* resolution with 14 bits, 2.5 µm stroke





Open Loop Positioning Accuracy

- **Open loop controller linearizes response**
- **Prevents snap-in failures by limiting controls to safe operating region - “reachable space”**



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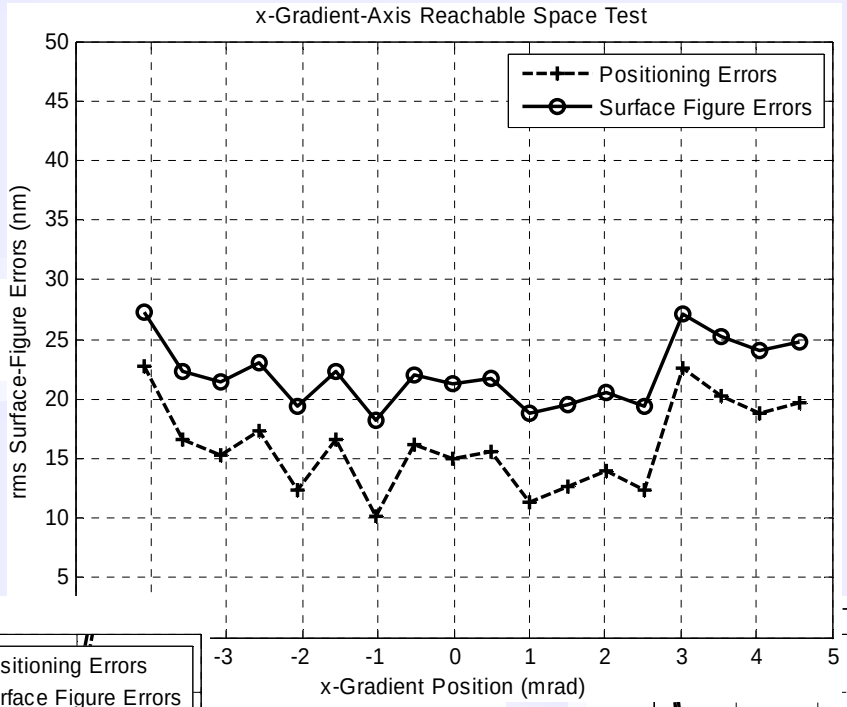
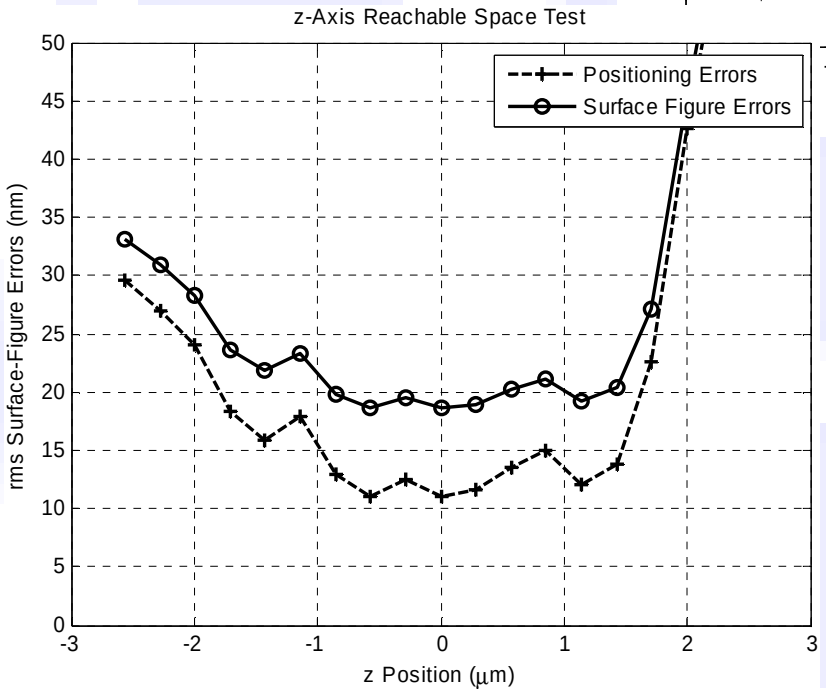
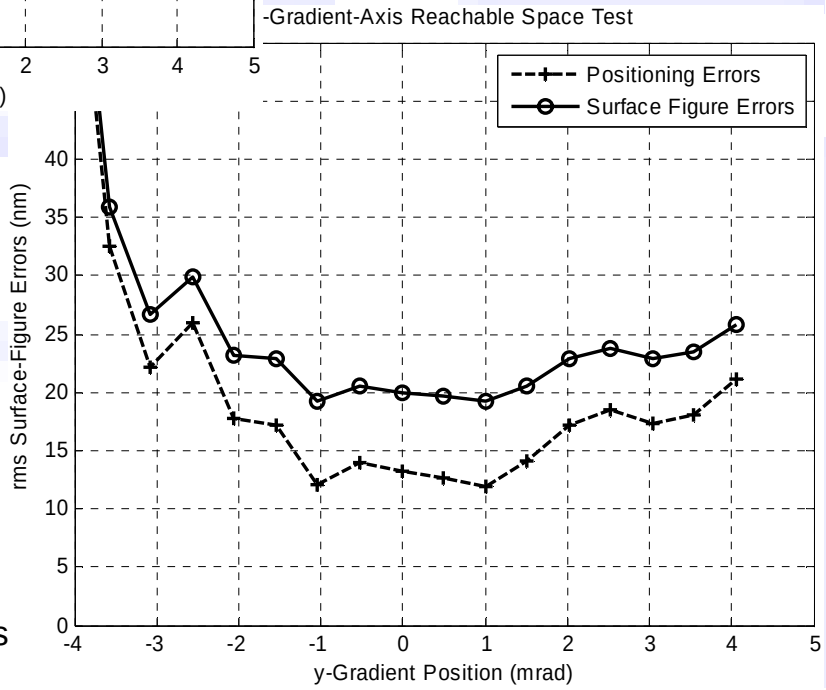
Open-Loop Positioning Accuracy







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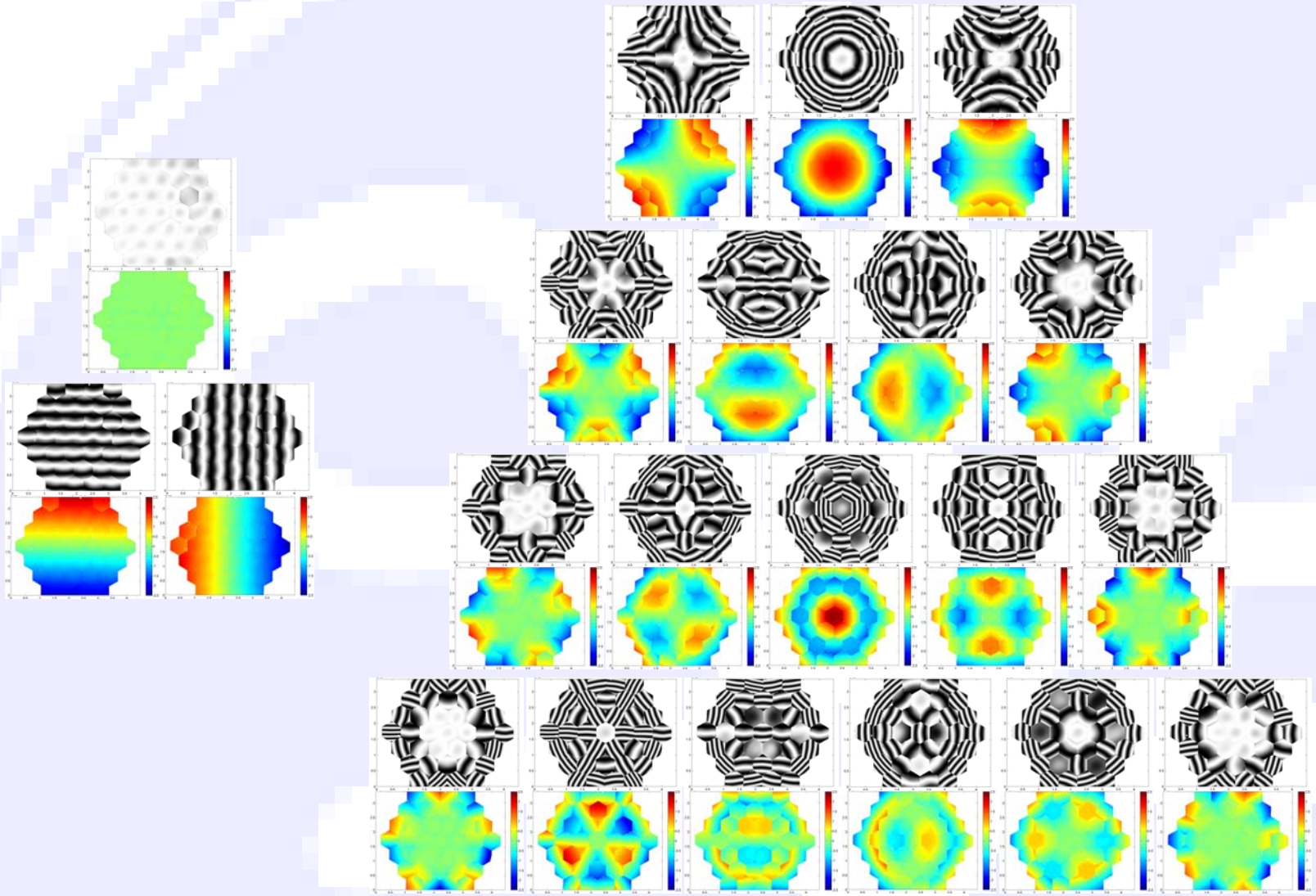
Open-Loop Positioning Example



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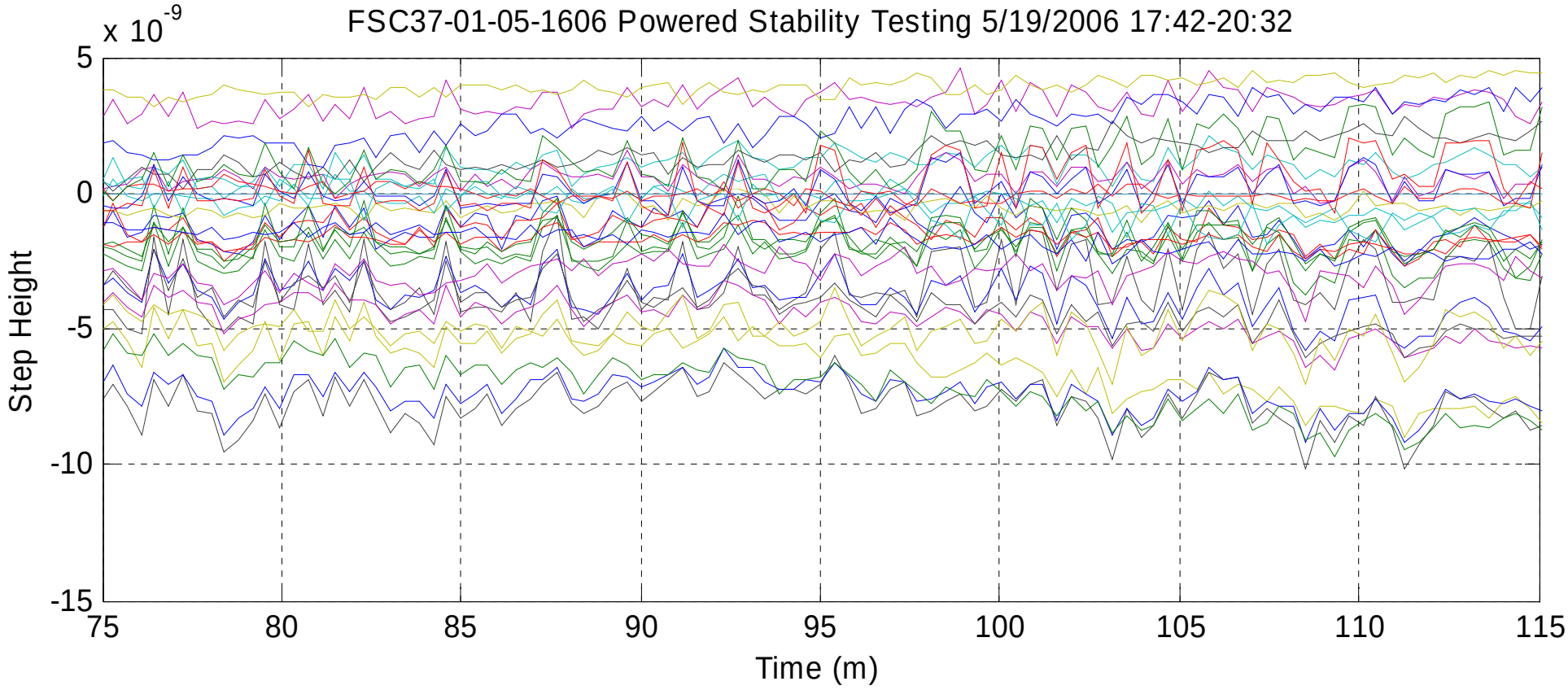
nm-Level Positioning Stability



- **Stability to 0.21-1.17 nm rms over 15 best minutes (75-90)**
- **Interferometry does not pick up electronics noise**
- **Temperature stable to 0.2°C**
- **Independent testing to be done by the CfAO/LAO**

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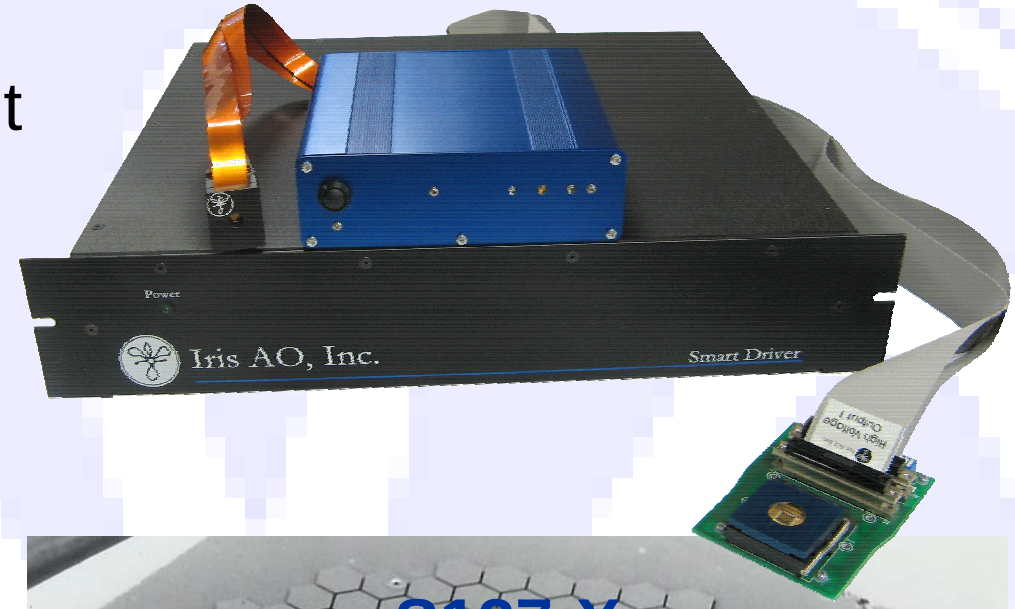
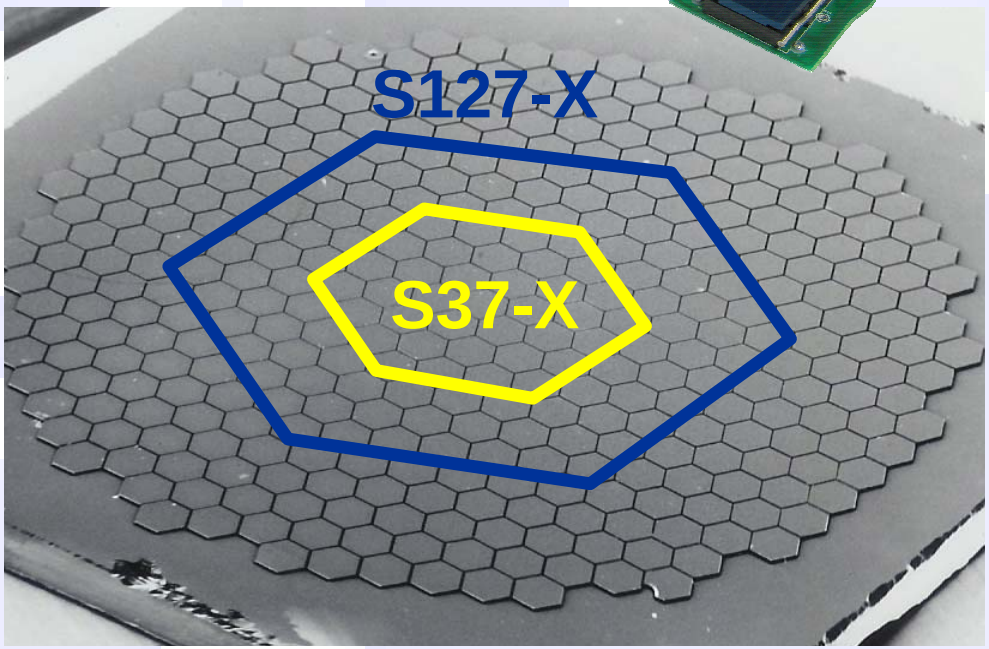
Scalability

- Currently selling 37-segment DMs
- Scalable drive electronics
  - NASA Phase II SBIR
- 127-segment DM
  - Funding from NIH Phase II SBIR under administrative review
- 400-1200 segment DM
  - Funding TBD
  - Preliminary experiments where possible
    - Bonding experiments underway





Summary

- Presently shipping 5 µm stroke, 37-segment DMs
  - 20 nm *rms* surface figures errors
  - 14.5 bit control, 5 nm *rms* noise floor
  - Precision open-loop positioning
  - Stable DM
- Phase II Progress
  - Low-noise Electronics mostly assembled
    - Testing begins September
  - DMs with flatter segments nearly complete
    - Testing begins September
    - Expect DMs with 3-12/2-8 nm *rms*

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Acknowledgements

Funding

- NASA – Phase II SBIR, (Extreme Precision DM Testing and Development)
  - NNG07CA06C
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  - 1 R43 EY015381-01
- US Air Force – Phase II SBIR (DM Control)
  - FA8650-04-M-6518