



Developments of high-density piezoelectric DMs with hysteresis control

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What Technology for DMs?

DM Parameters	Stacked Array Mirrors
Temporal Response	✓ Typically high: >10kHz
Number of Actuators	✓ Can be very high
Actuator Pitch	✓ Low (woofer) and ✓ High (tweeter)
Actuator Stroke	✓ Typically 3-10 μm
T°C Sensitivity, linearity	✓ Almost insensitive to T°C, Linear (for PZT, not PMN)
Close-loop AO Open-loop AO	✓ No problems ✗ Because hysteresis, but...
Applications* - VLT - MCAO (E-ELT) - SCAO (E-ELT) - XAO (E-ELT)	✓ Technology ready to use ✓ Technology ready to use ✓ Technology nearly ready but needs prototyping ✗ Technology suited, still in development

Stacked array DMs (SAM) is the most attractive technology for Adaptive Optics applications including ELTs*

* P.-Y. Madec, "Overview of Deformable Mirror Technologies for Adaptive Optics and Astronomy", Proc. SPIE 8447, Adaptive Optics Systems III, 844705 (September 13, 2012)

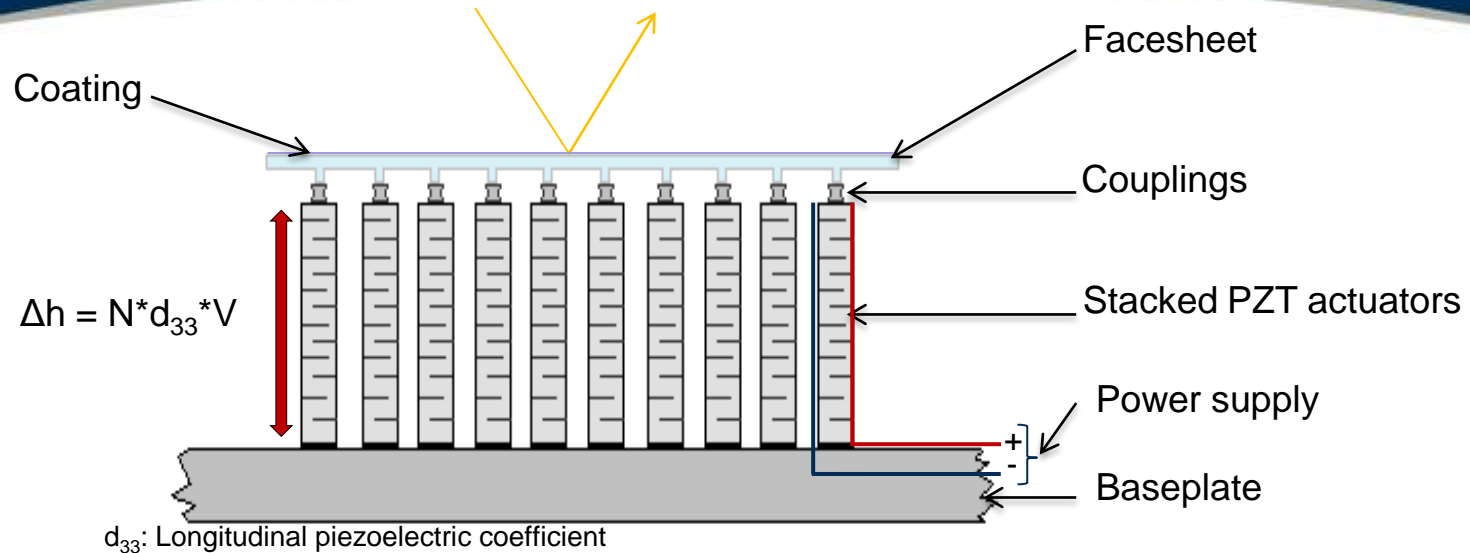


Presentation Outline

1. PZT Deformable Mirrors
 - a. General Concept
 - b. Characteristics
2. Overcoming Hysteresis
 - a. Capacitance Method
 - b. Frequency Method
 - c. Results
3. Future work & Conclusion



General DM Concept (1)



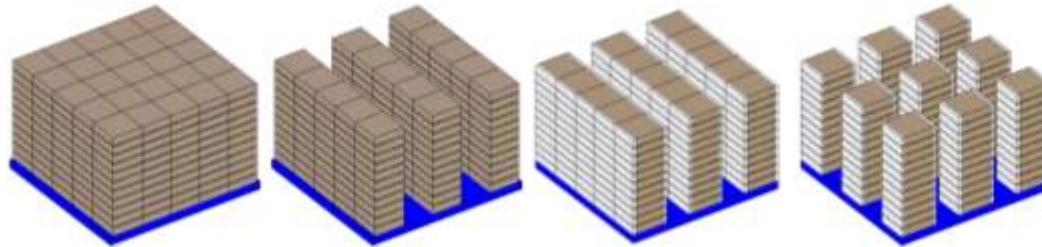
Main design drivers

- Small size & High actuator count: Pitch = 1.27 mm (goal 1mm)
- Large stroke: 3 μ m (goal 6 μ m)
- Operational range: room & cryogenic temperatures
- Low Hysteresis: < 1%
- Low power consumption
- Keep to cost down

General DM Concept (2)

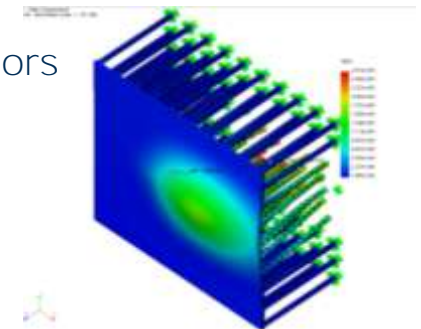
- Assembly Process (simplified)

- Thick PCB baseplate with embedded electric connections
- PZT block assembled to PCB, lapped, diced and add conductive material



- Optical surface

- Silicon with etched legs on the back connect to PZT actuators
- Silicon mirror bonded to PZT

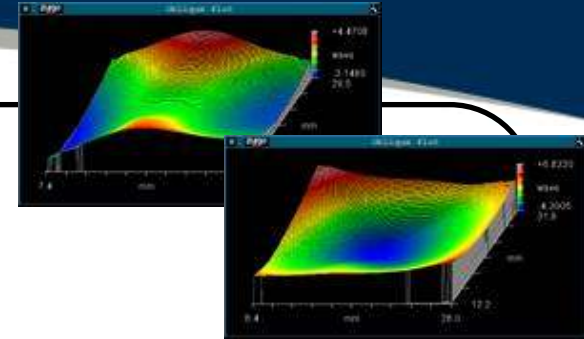


M. Strachan et al, "Novel technologies for small deformable mirrors", Adaptive Optics Systems II, Proc. SPIE Vol. 7736



Characteristics

- Small 6x6-actuator DM
 - Mirror coated with highly reflective dielectric
 - Simple drive electronics
 - Drive electronics with extension sensing (capacitance method)
- Designing a prototype with 14x14 actuators
 - Currently investigating inclusion of extension sensing (frequency method)



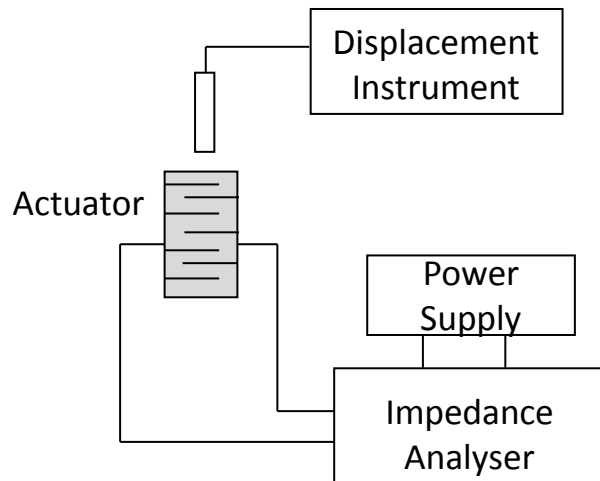
Parameters	Value		Comment
Number of Actuators	6x6 ⁽¹⁾	14x14	(1) Prototype being tested in laser applications ✓
Actuators Spacing	2.54 mm	1.27 mm	
Maximum Voltage	180V	80V ⁽²⁾	(2) Achieved by ↘ layer thickness
Individual Stroke	2-2.5 μm	2-2.5μm ⁽³⁾	(3) Expected stroke
Pupil Diameter	20*20mm ²	20*20mm ²	
Hysteresis	20% / <5% ⁽⁴⁾	1-5%	(4) For 2 nd generation of 36-actuator



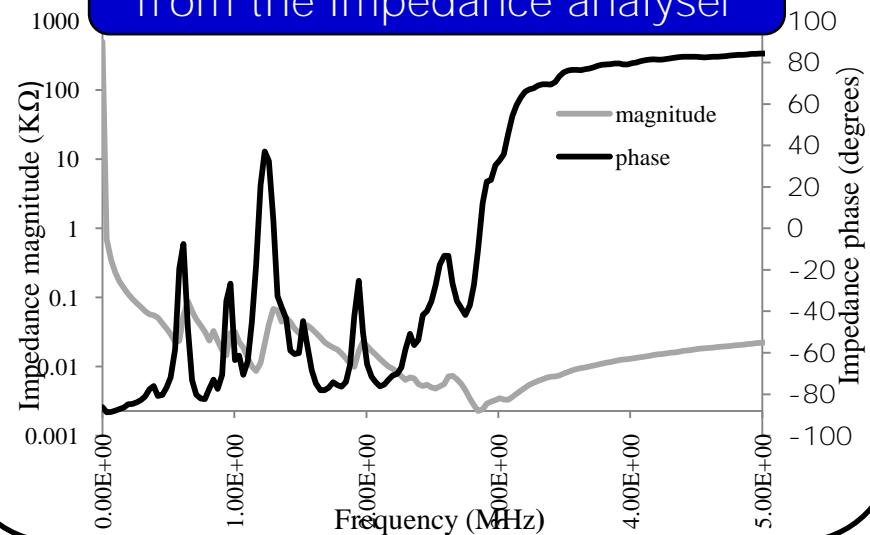
Overcoming Hysteresis

- 2 methods for measuring actuators extension were developed
 - Based on capacitance
 - Based on frequency
- Laboratory set-up: use of impedance analyser (can monitor actuator capacitance and frequency)

Simplified instrumentation set up for both methods



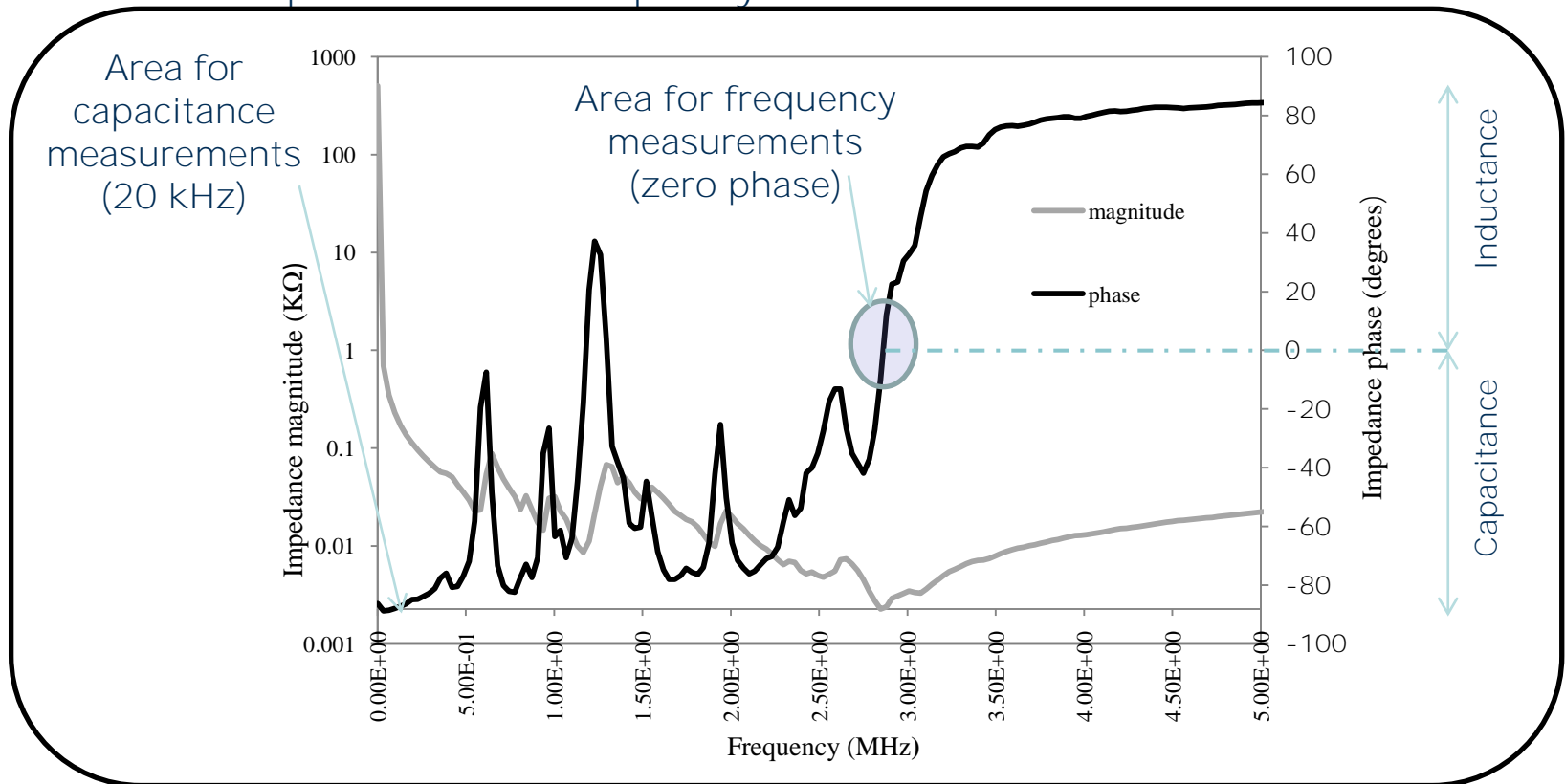
Impedance spectrum collected from the impedance analyser



E. Bryce et al, "Overcoming hysteresis in multilayered piezoceramic actuators used in adaptive optics", in Behavior and Mechanics of Multifunctional Materials and Composites 2012, Proc. of SPIE Vol. 8342

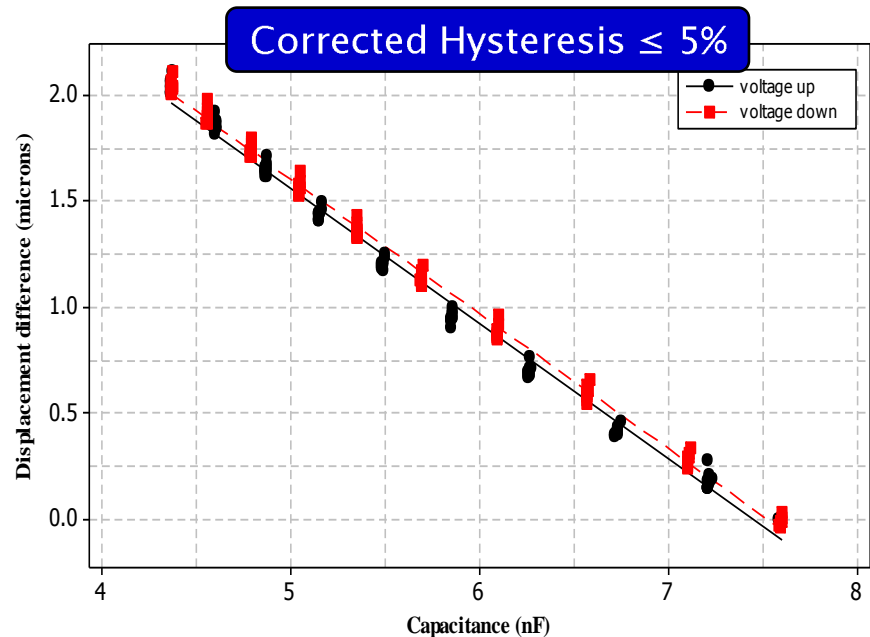
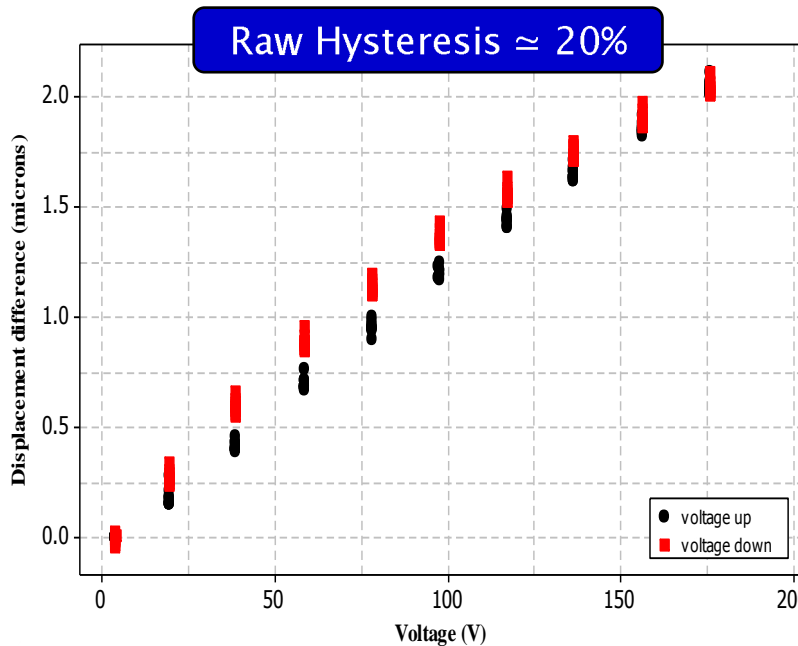
Actuator Impedance Spectrum

- Two areas of interest in the spectrum
 - Lower frequency end (20kHz) for the capacitance method
 - At zero-phase for the frequency method



Capacitance Method (1)

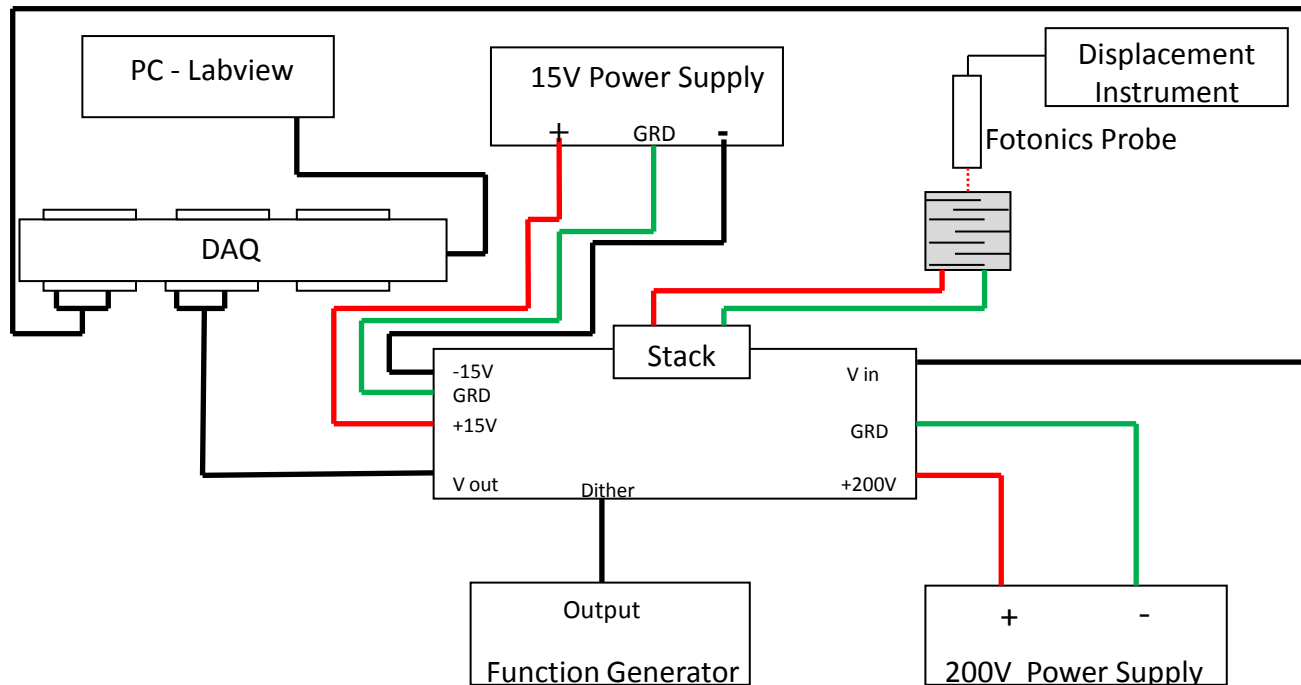
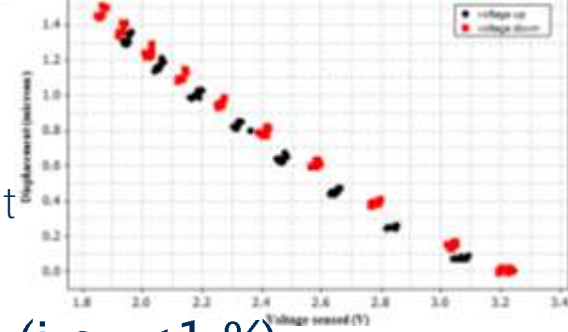
- Capacitance relates to extension
 - $C = \epsilon_0 \epsilon_r A / \Delta h$
- Raw hysteresis is ~20%
- **Corrected hysteresis $\leq 5\%$**
 - Very stable & repeatable method to compensate for hysteresis



Capacitance Method (2)

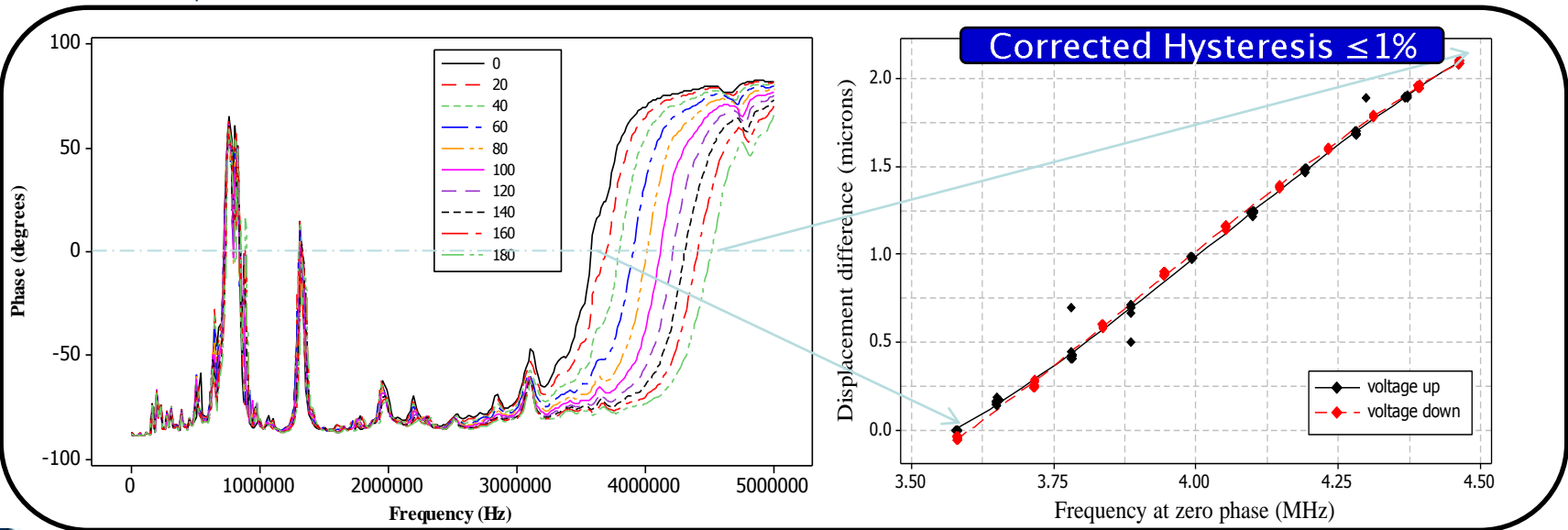
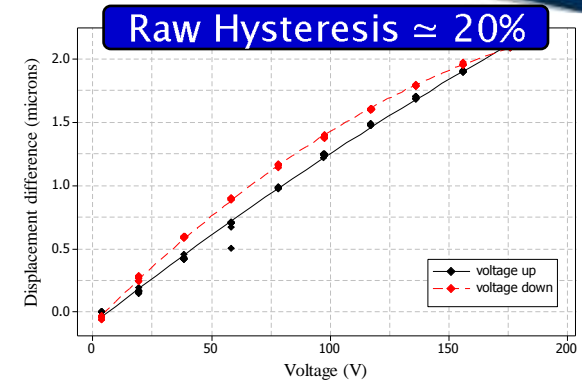
Corrected Hysteresis $\leq 5\%$

- DM Electronics drive with extension sensing
 - Currently testing integrated electronics
 - The capacitance method based voltage measurement
 - Simple measurement and electronics
- Cannot achieve requirement for ELT-MOAO (i.e. $\leq 1\%$)



Frequency Method

- Frequency at zero phase
 - Varies with applied voltage
 - Is related to the extension of the actuator material
- Displacement v. frequency at zero phase
 - Hysteresis < 1%
- Frequency method is sensitive
 - Ongoing work to standardise electronics & provide repeatable measurements



Conclusions & Perspectives

- Capacitance method
 - Hysteresis of $\approx 5\%$; Reliable and repeatable method
- Frequency method
 - Hysteresis better than 1%; On going work to improve robustness
- Low-order DMs with 6x6 actuators tested
 - Good performance for laser applications
 - Circuit using the capacitance method designed & being tested
- **'High-order'** DM with 14x14 actuators being assembled
 - Smaller pitch, improved assembly process
 - Ongoing work to incorporate frequency method to the drive electronics
- Drive electronics
 - Developing a novel strategy to drive large arrays
- DM assembly
 - Hydroxide-catalysis bonding, a promising for cryogenic DMs
- Increase actuator stroke to $6\mu\text{m}$

