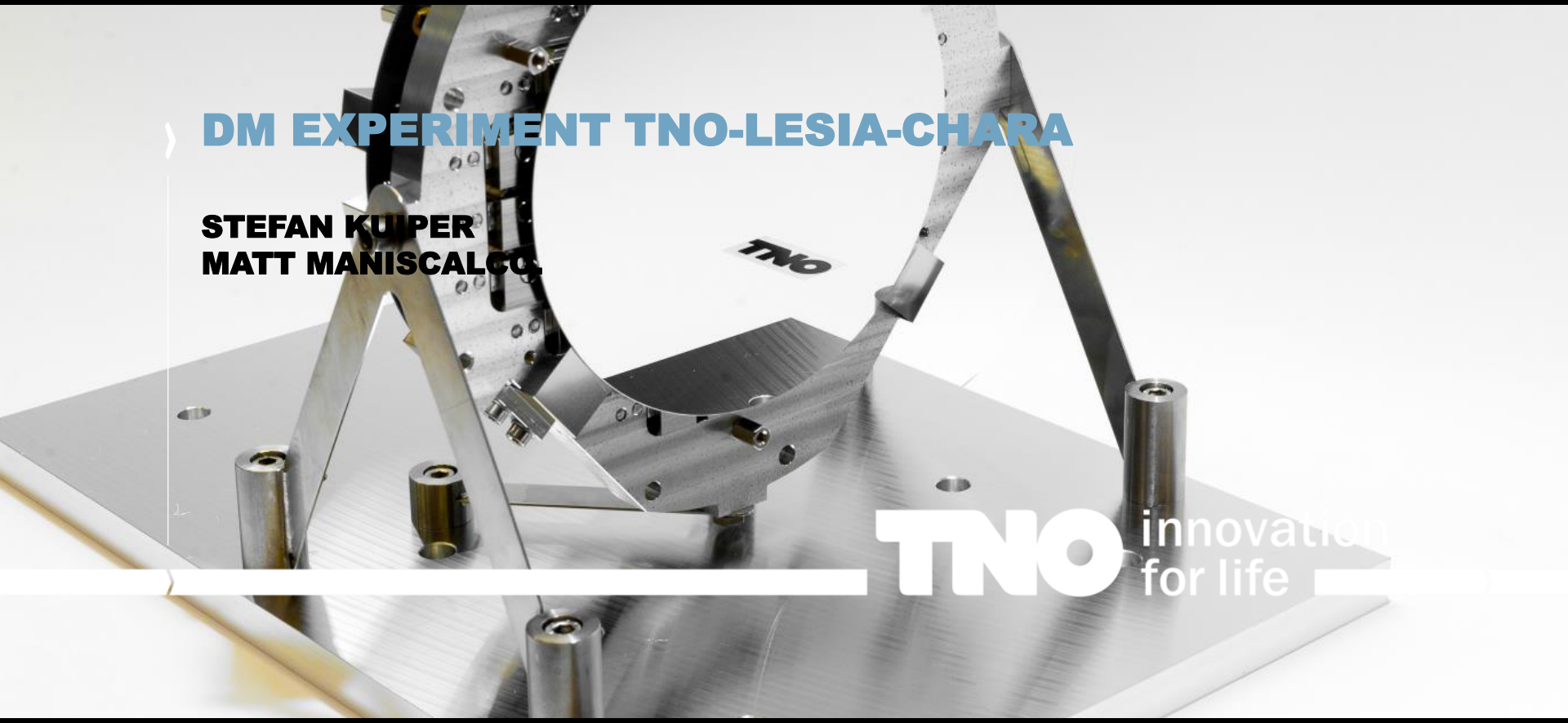


DM EXPERIMENT TNO-LESIA-CHARA

STEFAN KUIPER
MATT MANISCALCO

TNO innovation for life

CONTENT

1) Introduction TNO
2) DM technology
3) DM experiment
4) Conclusions & Outlook

WHO WE ARE

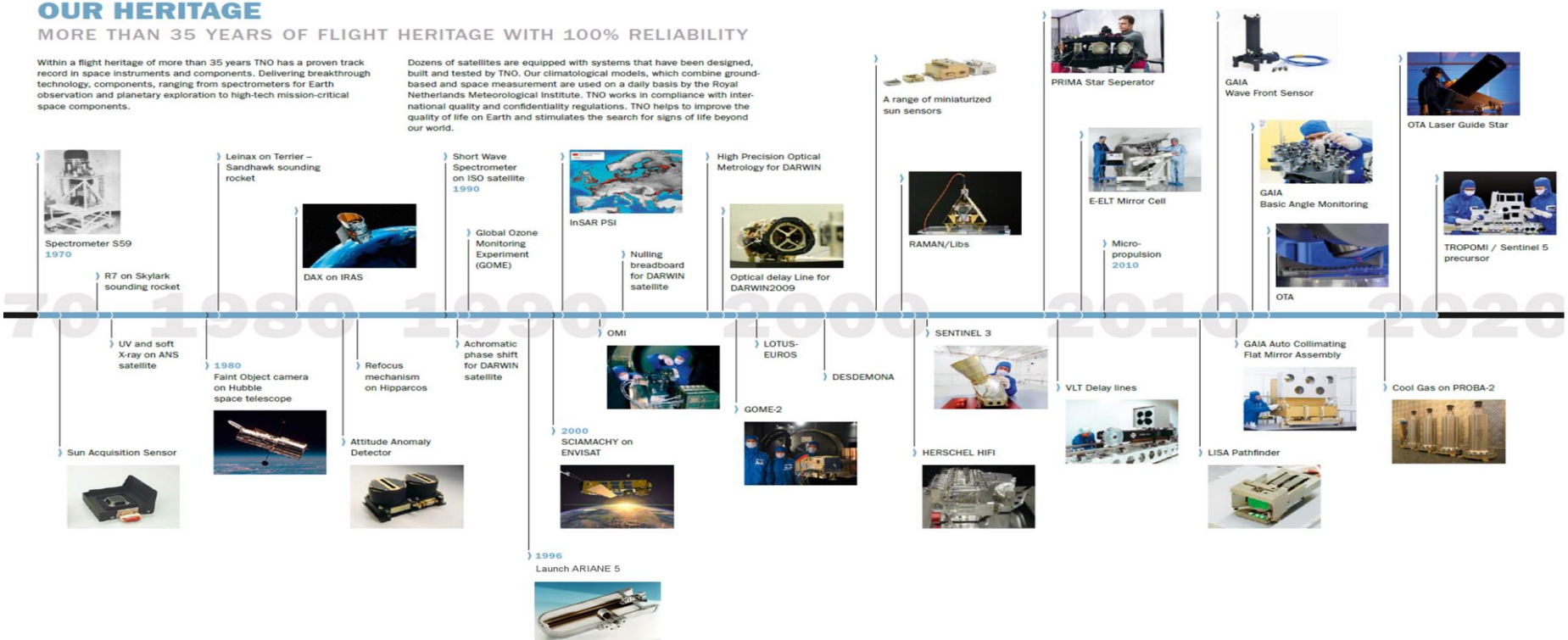
- Netherlands Organization for Applied Scientific Research
- Established by law in 1932
  - to bridge the gap between academia and industry
  - assisting companies to innovate by doing R&D
- About 3500 employees

OUR HERITAGE

MORE THAN 35 YEARS OF FLIGHT HERITAGE WITH 100% RELIABILITY

Within a flight heritage of more than 35 years TNO has a proven track record in space instruments and components. Delivering breakthrough technology, components, ranging from spectrometers for Earth observation and planetary exploration to high-tech mission-critical space components.

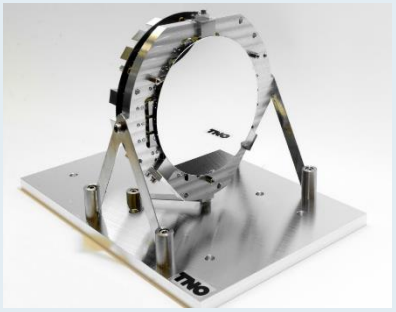
Dozens of satellites are equipped with systems that have been designed, built and tested by TNO. Our climatological models, which combine ground-based and space measurement are used on a daily basis by the Royal Netherlands Meteorological Institute. TNO works in compliance with international quality and confidentiality regulations. TNO helps to improve the quality of life on Earth and stimulates the search for signs of life beyond our world.



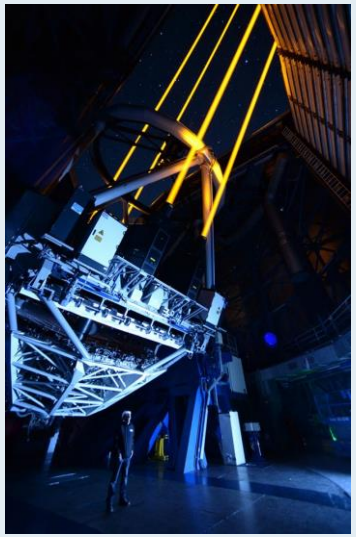
TNO'S EXPERIENCE WITH AO

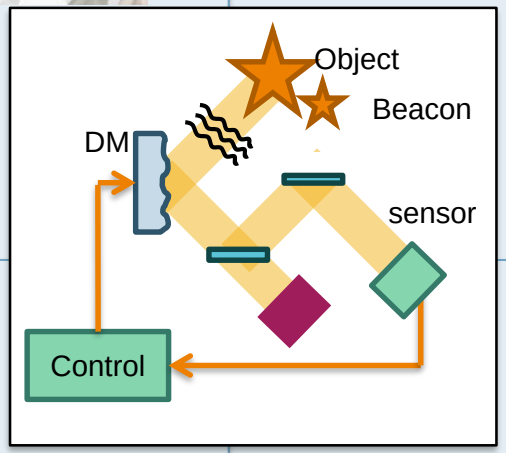
- Application fields; Ground based astronomy, Semiconductor, Laser Communication, and Space

Corrective elements

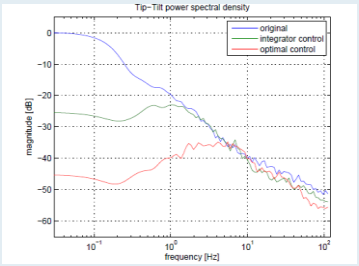


Beacon





Control



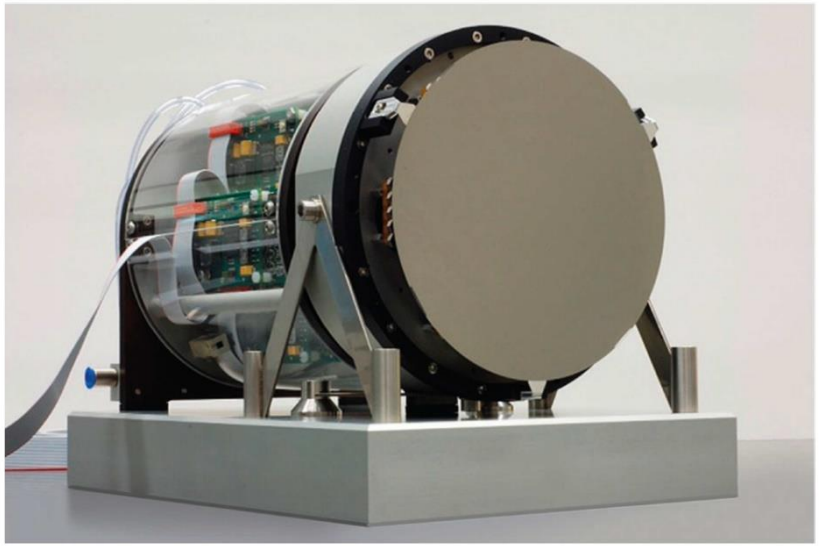
Wave front sensing

DM DEVELOPMENT AT TNO

- DM development started in 2004
- Upgrade started in 2016 with improved actuator efficiency
- Target applications: Astronomy, Space, and Laser communication, Lithography

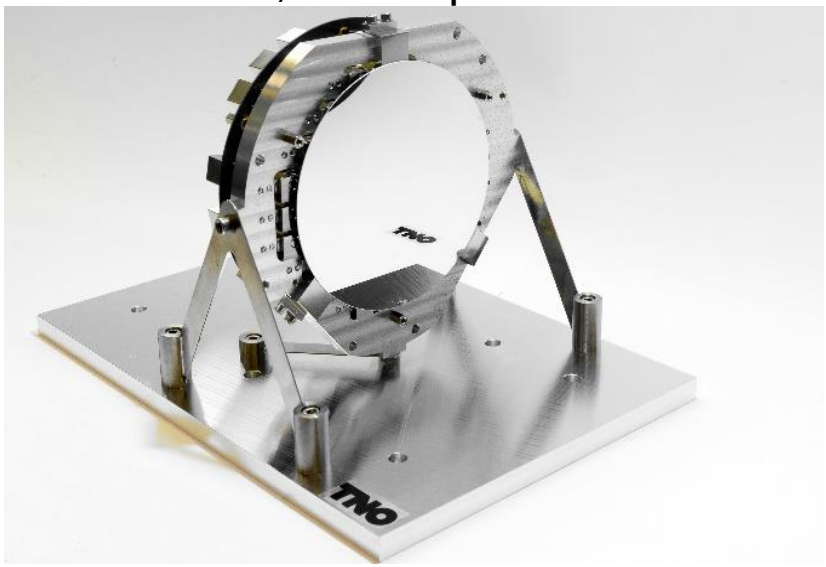
Prototype 2010

427 actuators, 6mm pitch



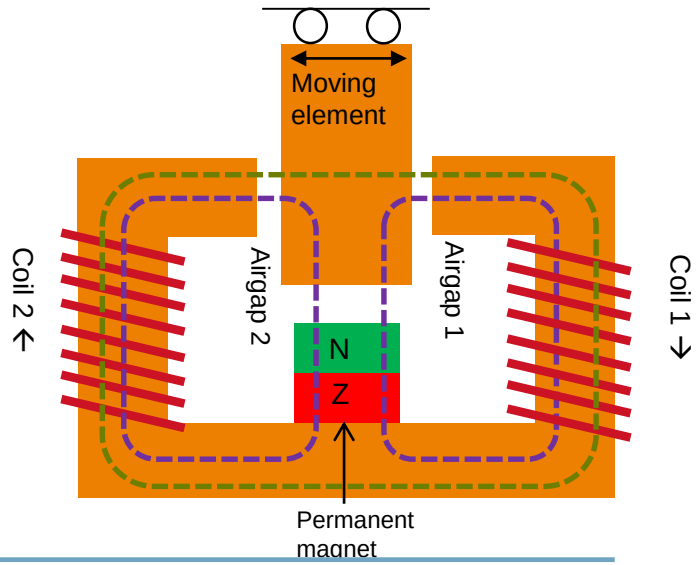
Prototype end- 2016

57 actuators, 18mm pitch

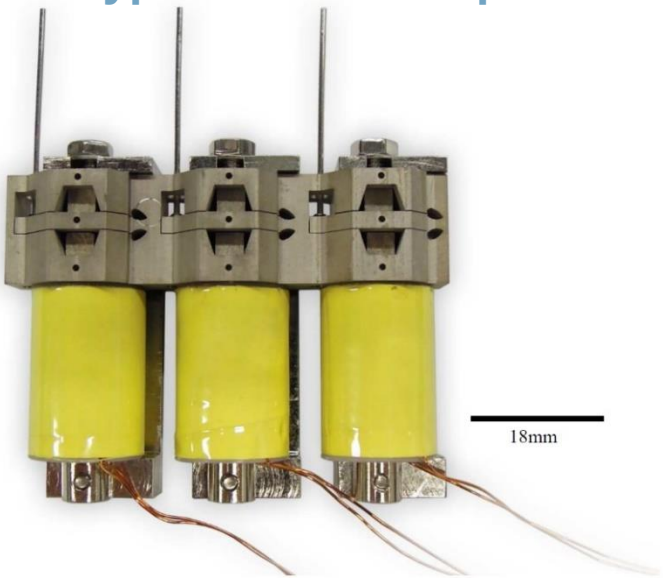


ACTUATION PRINCIPLE

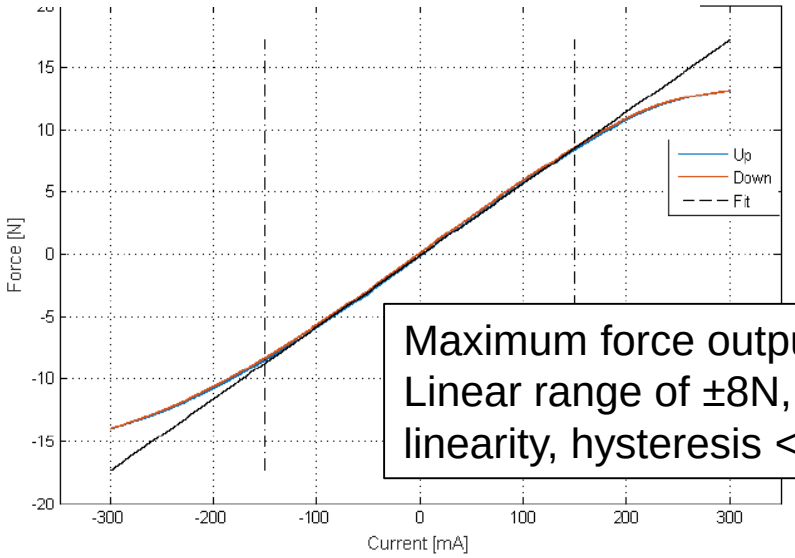
- Actuation principle; **variable reluctance**
- **High efficiency** in terms in volume and power
- Highly linear response (>99.5%)



Prototype actuator strip



Test results: **Force-Current**

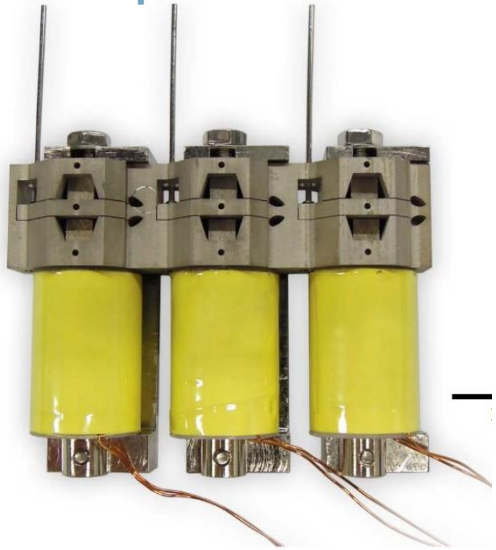


Maximum force output ± 14N
Linear range of ±8N, 99.5% linearity, hysteresis <1%.

MAIN ASSETS

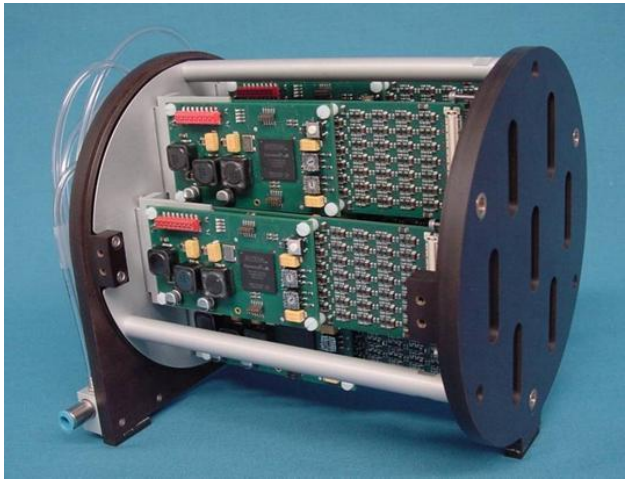
1. **High reliability** ; (i) No wear/aging, (ii) Compliancy (iii) redundant windings
2. **High linearity, repeatability and stability** (compatible with slow AO update rates)
3. **Low power dissipation** (~ few mWatts per actuator)
4. **Compact, low power electronics** (PWM)
5. **High force per volume;** Scalable to large apertures, and actuator pitches

18mm pitch actuators



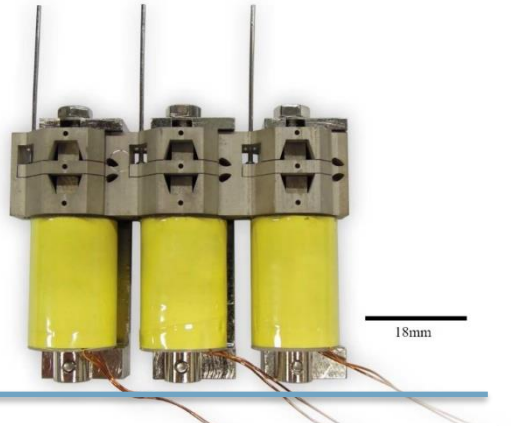
4,3 mm pitch actuators

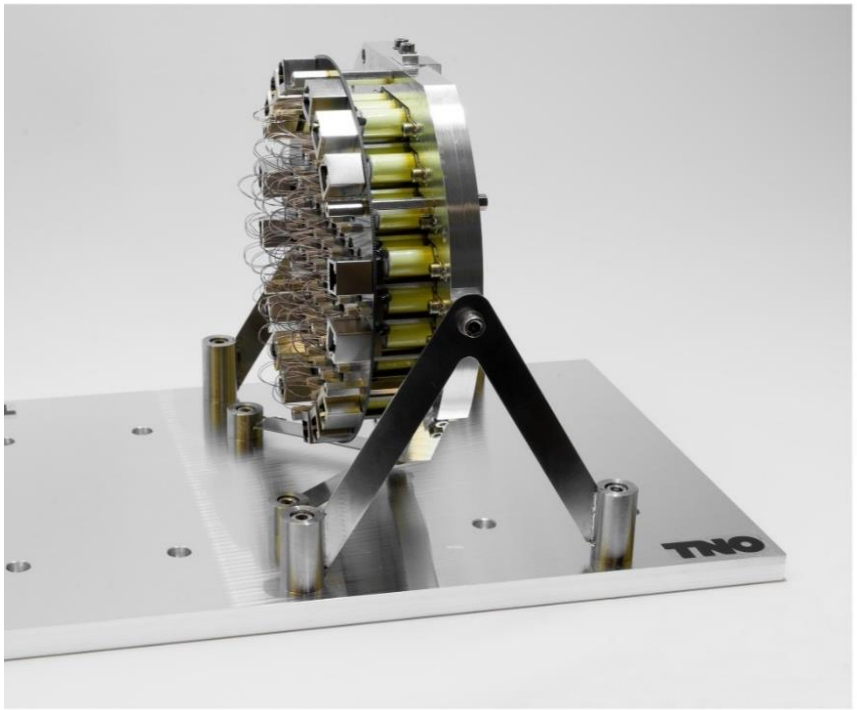
PWM drive electronics

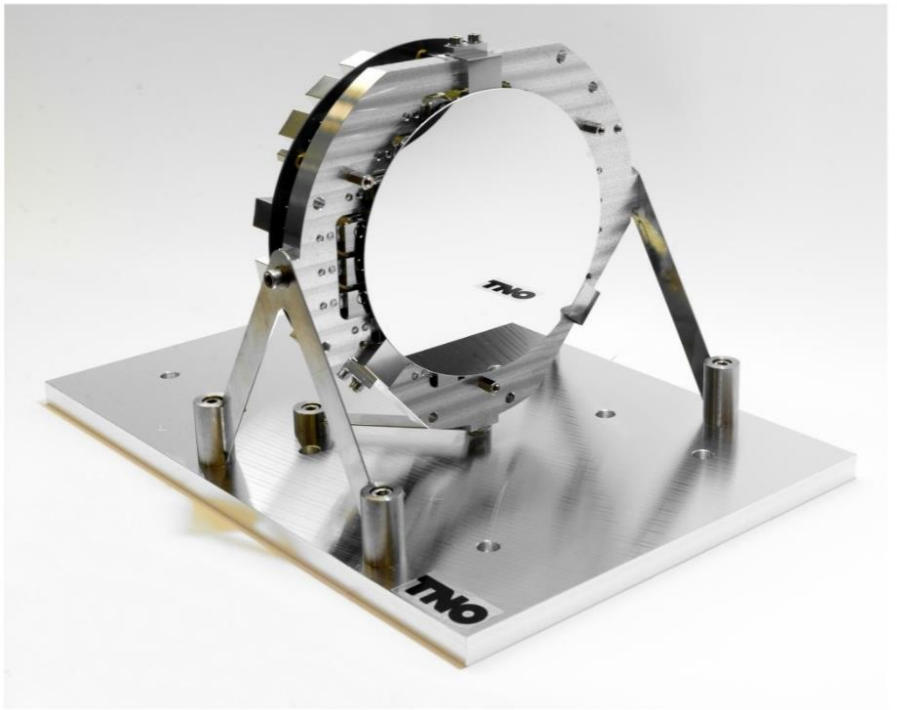


DEFORMABLE MIRROR PROTOTYPE

- Proto integrated end 2016
- 57 actuator prototype, (18mm pitch)
- Ø160mm diameter mirror, (1mm fused silica)
- Free stroke 40µm PV, Inter-actuator stroke 10µm PV
- Kinematic face sheet interface (thermal stability)





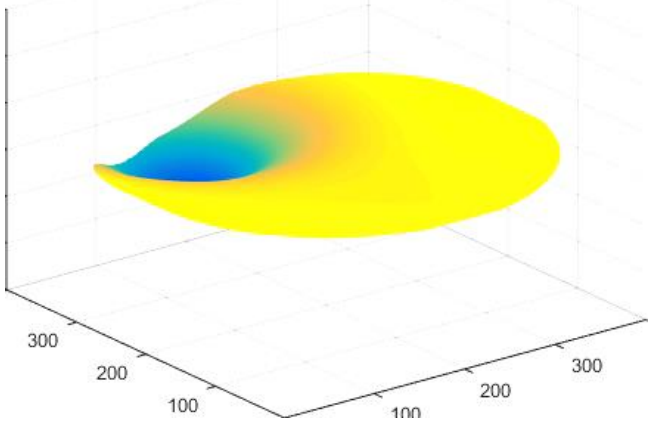


DM TEST RESULTS

- **99%** Linearity confirmed
- Best flat performance **32nm RMS**

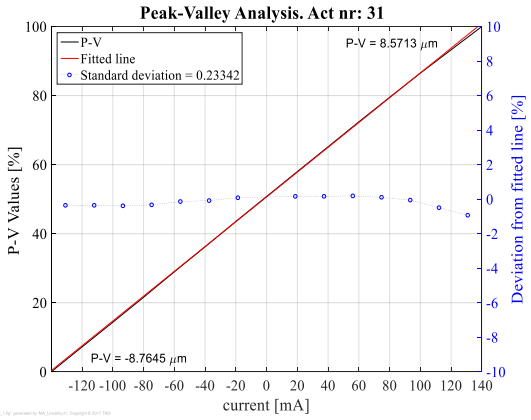
  (currently limited by COTS face sheet)
- **>0.9 shape** purity in un-calibrated Openloop shape control
- Power dissipation for flattening is **0.2 Watts** (total)

ACTUATOR RESPONSES



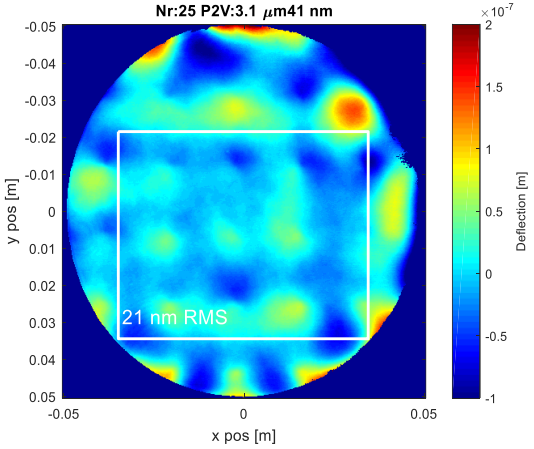
LINEARITY

Linearity > 99.5%



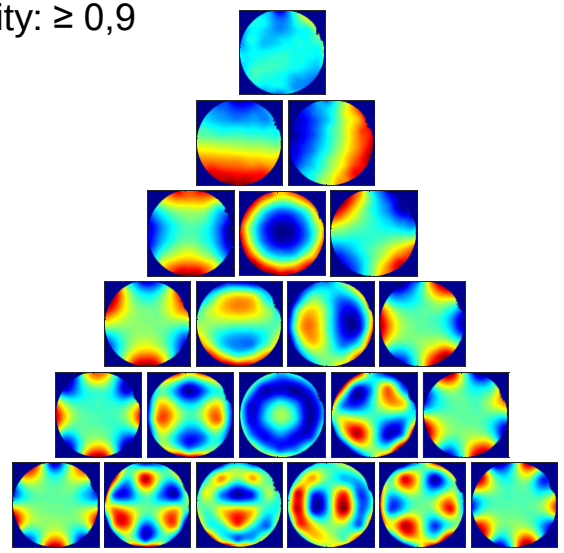
BEST FLAT

32 nm RMS (95% Apert.)



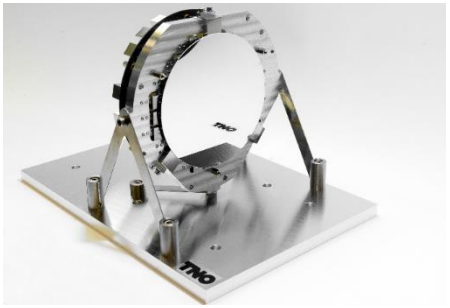
OPEN-LOOP CONTROL

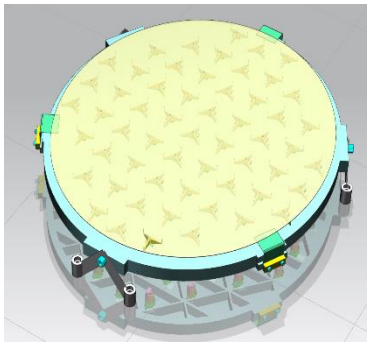
Purity: ≥ 0,9



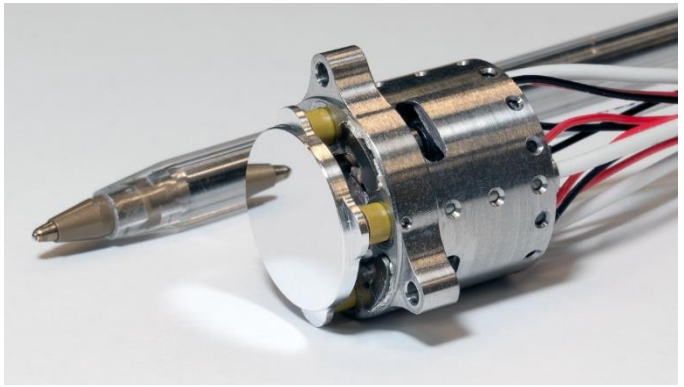
ONGOING DM PROJECTS

ESA TRP; AO for space telescopes



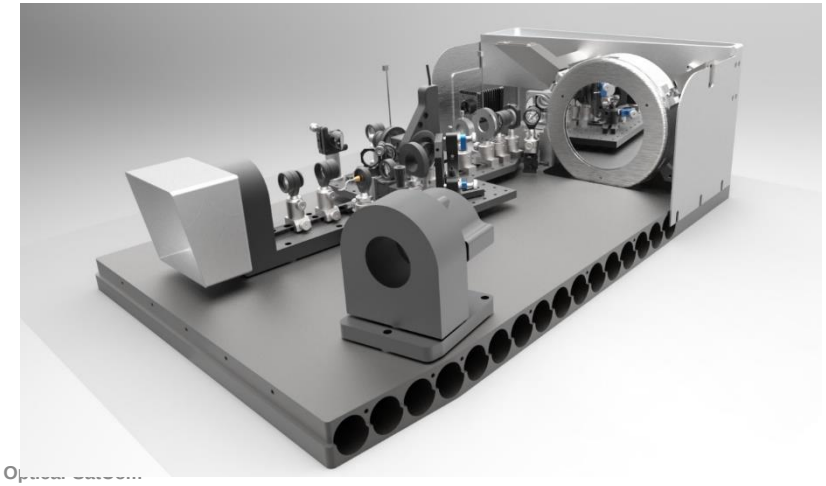


Fine steering mirror



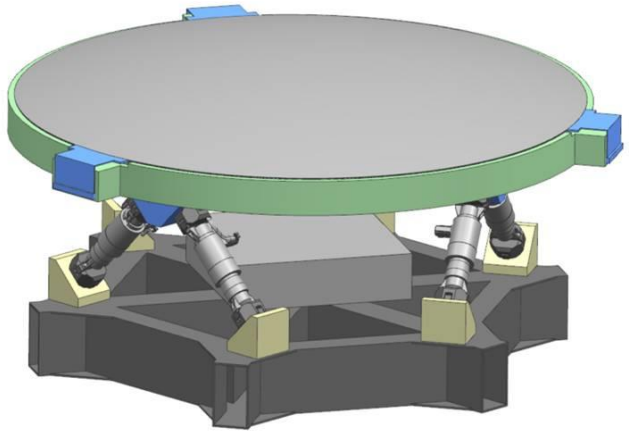
Optical Feeder Link

ESA project, Dynamic upgraded DM.



TMT Adaptive secondary study

Ø3m Concave mirror, 3462 actuators



DM EXPERIMENT TNO-LESIA-CHARA

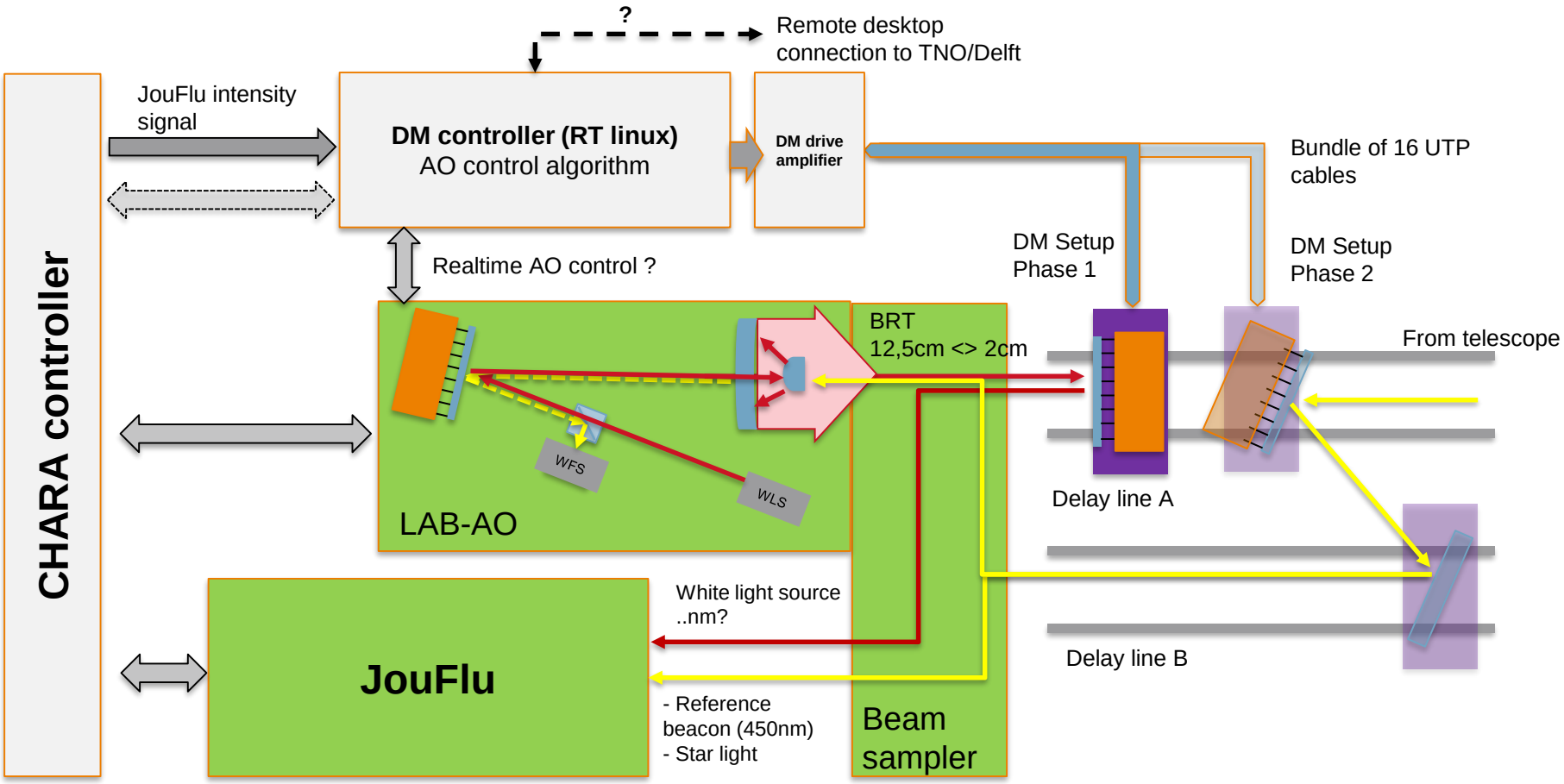
- **Project goals:** Improve fiber coupling efficiency of JouFlu via AO

- Compensate for quasi static aberrations from beam line optics
- Later experiments may include dynamic compensation of atmospheric turbulence

- 1th Phase; Verify functionality based on internal source
- 2nd Phase; Verify performance on sky (single channel)

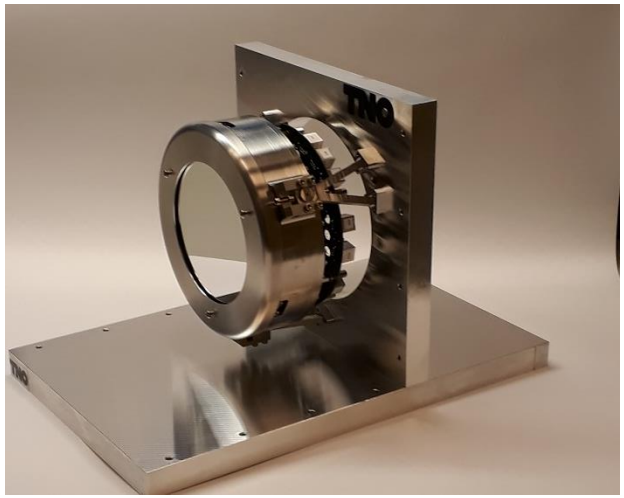
- Control strategy;
  - DM-shape optimization based on intensity signal
  - Extremum seeking algorithm

EXPERIMENT OVERVIEW



PLANNING (TBC)

- Finilized DM integration April-2018
- DM tested and calibrated May-2018
- First ‘hand-shake’ CHARA June-2018
- TNO control experiments Aug.-Sept. 2018
- Experiments at CHARA (phase 1) Sept-Okt 2018.



CONCLUSIONS

- TNO is developing DM's and FSM based on variable reluctance actuation
- Main assets; Reliability, Efficiency, and Repeatability

- Experiments planned, using DM to improve fiber coupling efficiency JouFlu.

ACKNOWLEDGEMENT

- Thanks to Theo ten Brummelaar, and Vincent Coudé du Foresto for setting up this opportunity!

BACK-UP

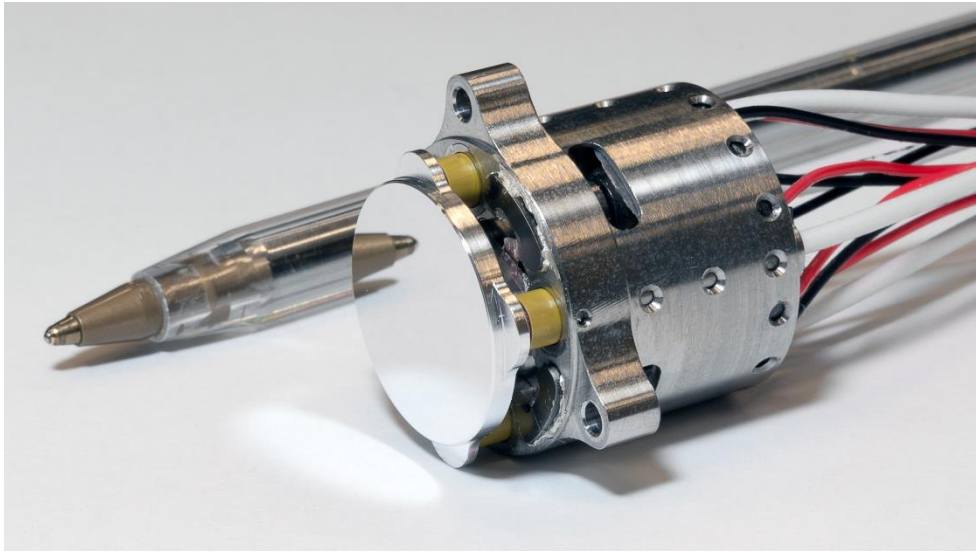
FINE STEERING MIRROR DEVELOPMENT

- Targeted for beam steering in inter-satellite laser communications

- Design features :
  - Custom developed reluctance actuators, redundant coil windings
  - Flexural bearing
  - Mirror angle control via eddy current sensors
  - Dedicated thermal design enabling high optical power

Main design Specifications	
Tip/tilt range	±2˚ (Optical)
Bandwidth (-3dB)	>1kHz
Jitter	< 1 µrads
Optical coating	Enhanced gold, >98% refl. @ 1550nm
Admissible Optical Power	~10Watts
Mirror diameter	Ø20mm
Volume	Ø24x30mm
Dependability	Redundant motor windings

FSM prototype



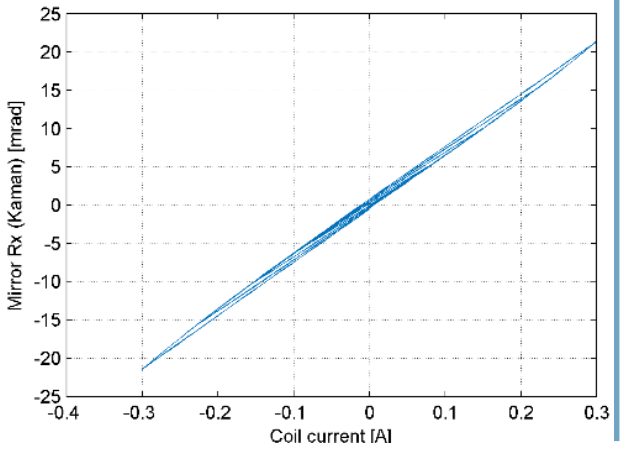
TEST RESULTS

- Actuation **stroke and efficiency verified**
- ±2˚ optical range (both axis)
- Closed loop bandwidth **> 1kHz**
- Currently undergoing lifetime testing

Open-loop FSM movement

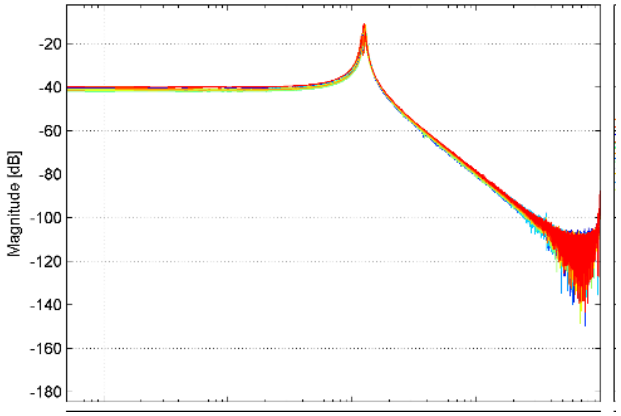
Open-loop response

±2˚ optical range (both axis)



Open-loop response

First resonance 120Hz
Smooth response up to >10kHz



Closed loop response

Control bandwidth >1kHz
High stability margins