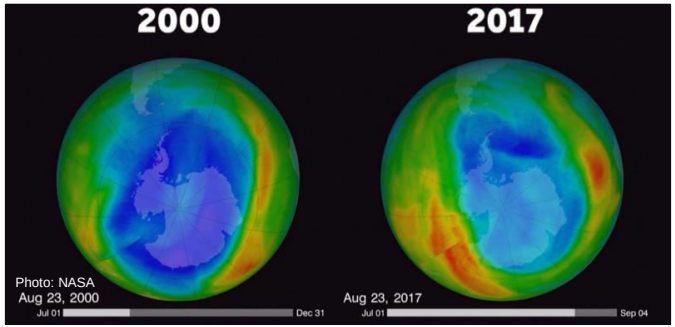
ADAPTIVE MIRRORS FOR ASTRONOMY

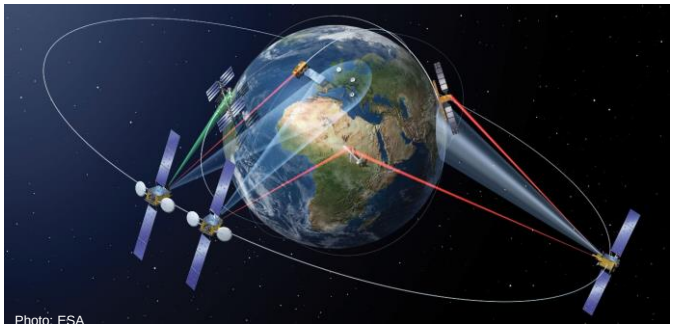
W.A. Jonker

TNO innovation for life

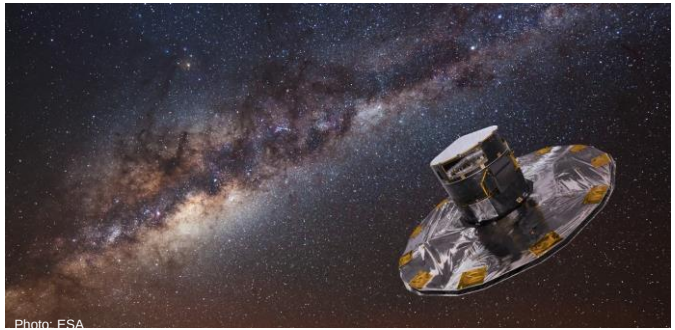
SPACE & SCIENTIFIC INSTRUMENTATION AT TNO



Preventing Climate Change



Secure Broadband Connectivity



Understanding the Universe

Economic growth in NL and EU

We build *prototypes and one-offs* to stimulate the *high tech industry* and enable *scientific discovery*

BIG SCIENCE: ELT M1 SUPPORT STRUCTURE

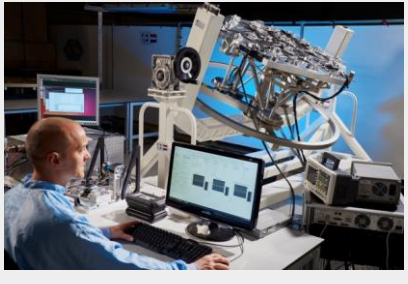
- ESO's Extremely Large Telescope has a 39m diameter mirror, consisiting of 798 hexagonal 1.4m segments
- M1 support structure keeps each segment of each shape within 22nm surface form error
- Warping harness actively corrects individual segment shape for gravity vector
- 1 EM & 6 QM's delivered meeting all specs
- Joint prototype development with the goal of securing volume manufacturing of **900+** units for NL

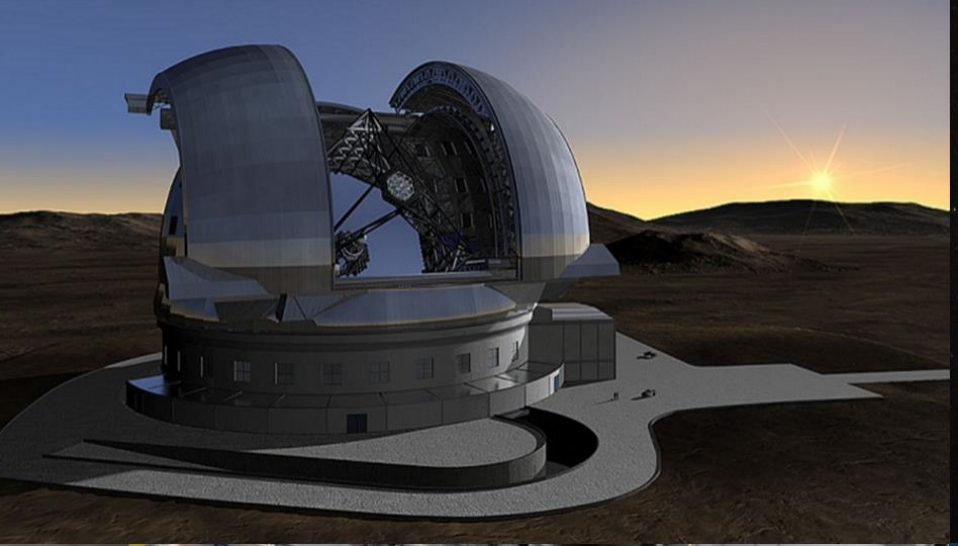
VDL ETG Projects, part of VDL Groep, will build the supporting structure for the main mirror of the Extremely Large Telescope (ELT) in northern Chile.

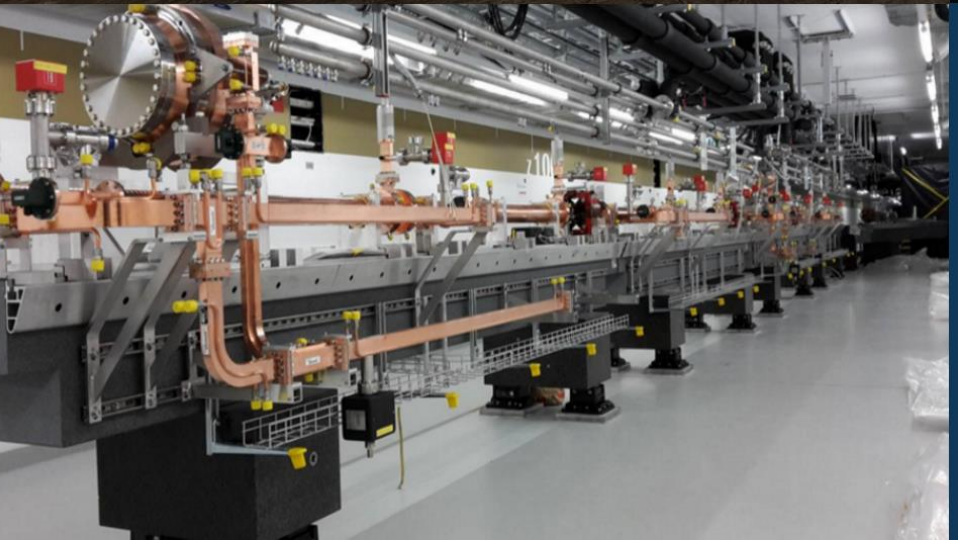
VDL works on building ‘the world's biggest eye on the sky’

19 April 2018

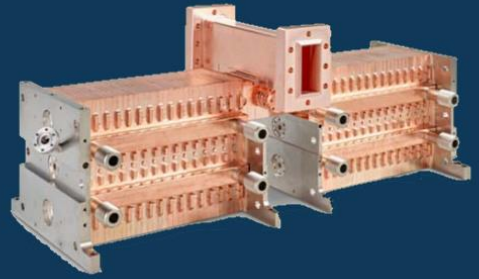
VDL ETG Projects, part of VDL Groep, will build the supporting structure for the main mirror of the Extremely Large Telescope (ELT) in northern Chile. At an elevation of over 3 km, this is where the ESO (European Southern Observatory) will build the world's largest telescope. The supporting structure consists of 798 individual support structures for mirror segments, which together form the telescope's main mirror (with a diameter of over 39 metres). The order, which VDL ETG Projects will deliver over the course of five years, is worth several tens of millions of euros.







VDL Science & Technology



VDL ETG Market Segments – high-end contract manufacturing

Semiconductor Capital Equipment

Mechanization Projects

Analytical Equipment

Led Manufacturing Equipment

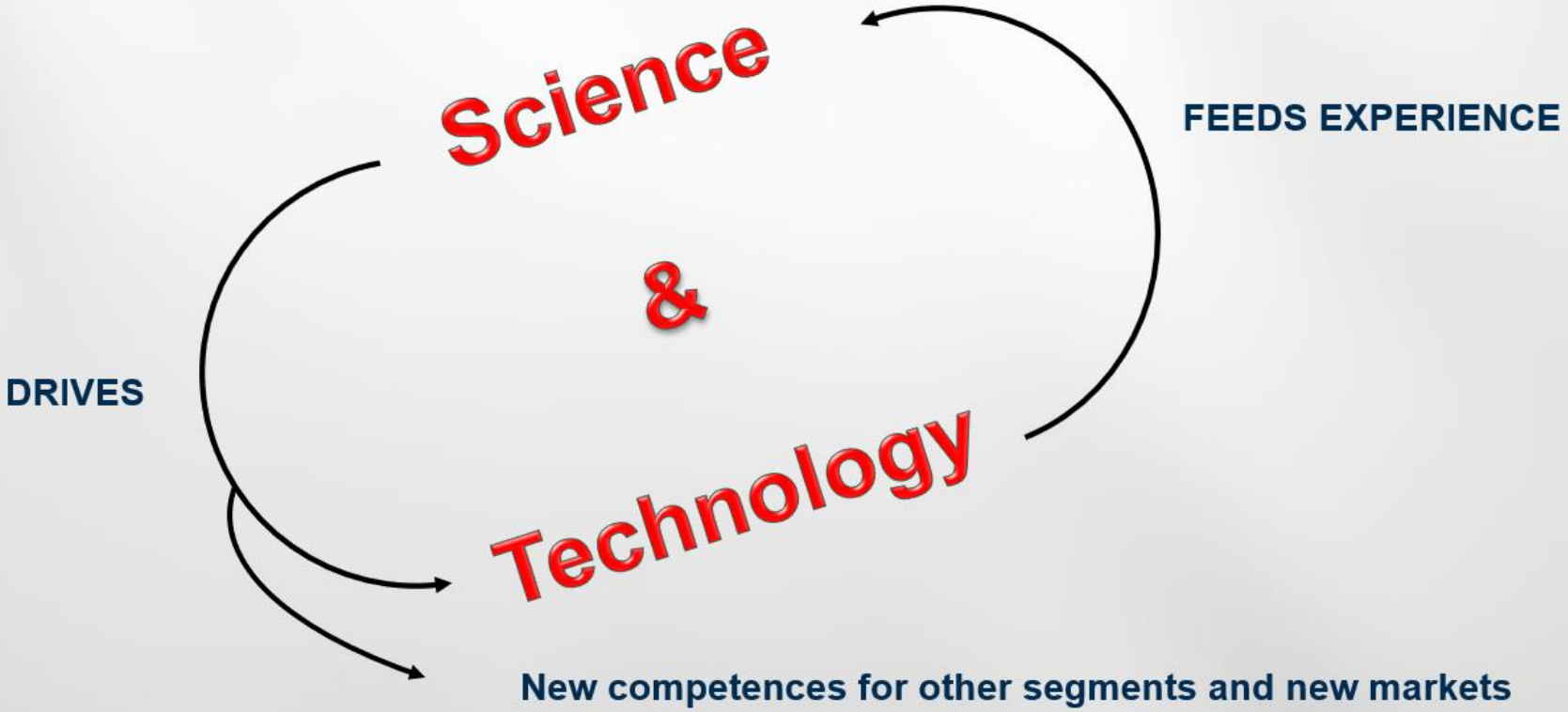
Medical Equipment

Solar Production Equipment

Science & Technology
- Accelerators & FELs
- Instruments for astronomy
- Satellites (communication, earth observation

Aerospace

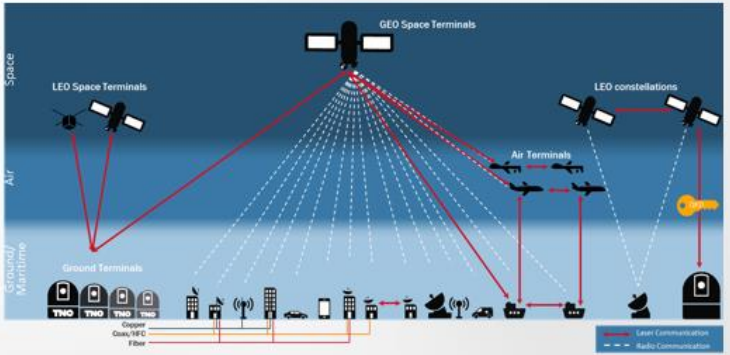
Science & Technology drives our competences

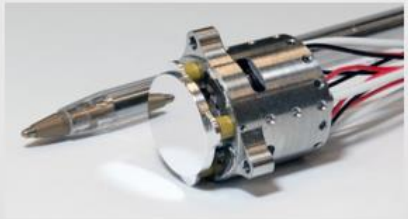


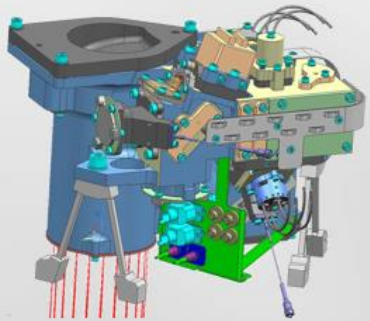
Space….optical communication

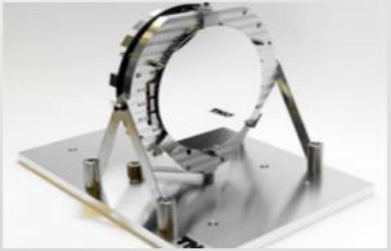
- VDL is member of a Dutch industry consortium bringing laser com technology to the market
- FSO Instruments, powered by TNO technology

FSO instruments



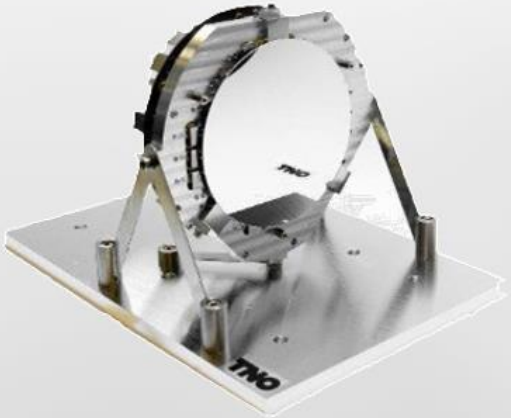






Next…(actuators for) adaptive optics

- Highly efficient deformable mirror
- Launching application: astronomy
- UH88: proof of concept / demonstrator
- International project – science, applied science, industry

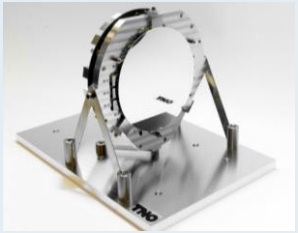


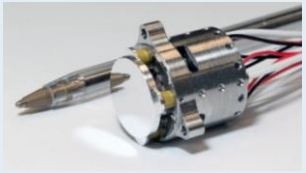
Deep dive: next slides

TNO EXPERIENCE WITH ADAPTIVE OPTICS

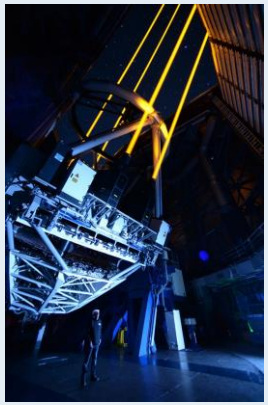
- Application fields; Ground based astronomy, Semiconductor, Laser Communication, and Space

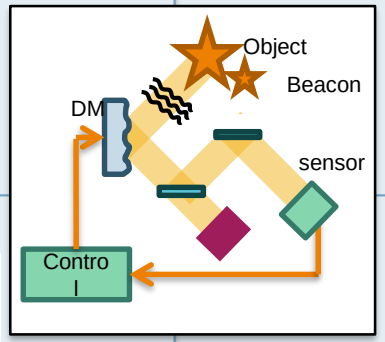
Corrective elements



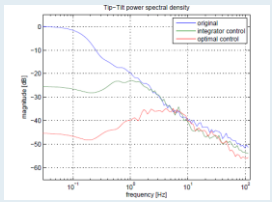


Beacon





Control



Wave front sensing

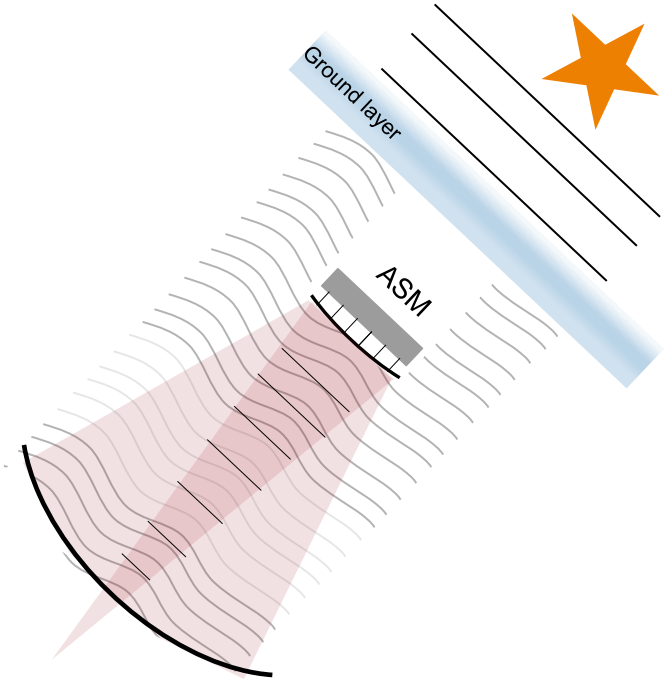
OPPORTUNITY: GLAO FOR ASTRONOMY

- **G**round **L**ayer **A**daptive **O**ptics (GLAO)
- Improve resolution over a wide field of view by compensating ground layer aberrations.

- Drivers for **A**daptive **S**econdary **M**irrors (ASM)
  - Wide field of view corrections
  - High-throughput and simplified optics
  - Minimize Thermal Background

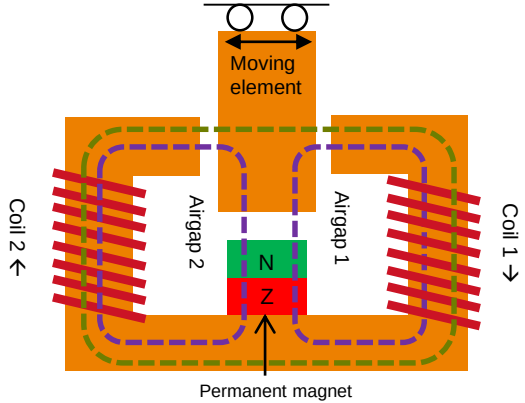
- Current adaptive mirrors are placed as separate instruments in the lab in the optical back-end of the telescope

- With ASM, AO becomes an integral part of the overall system
  - Reliability and robustness of critical importance

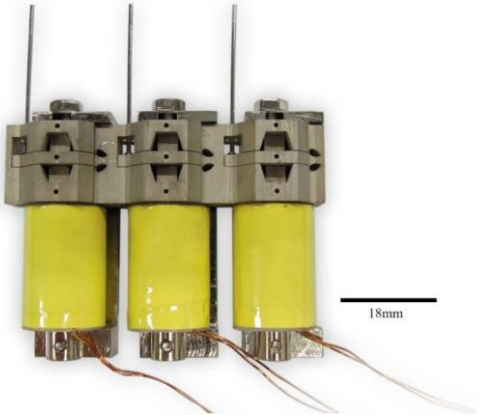


ACTUATOR TECHNOLOGY

- Actuation principle; hybrid variable reluctance
  - Highly linearity; repeatability; stability
  - High force per volume; scalable up from ~5mm pitch
  - Efficiency: 38 $N/\sqrt{W}$; 40x that of same size voice-coil
  - Low power dissipation (mW per actuator)
  - Compact, low power PWM electronics

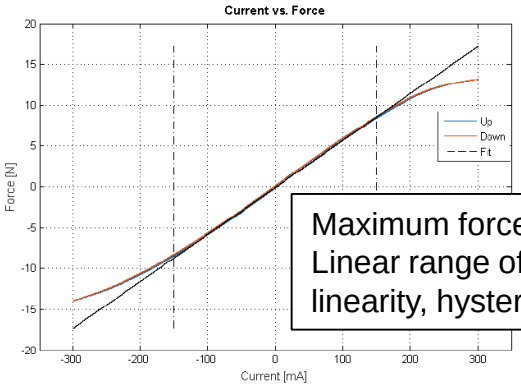


prototype actuator strip



4,3 mm pitch actuators

Test results: Force-Current



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

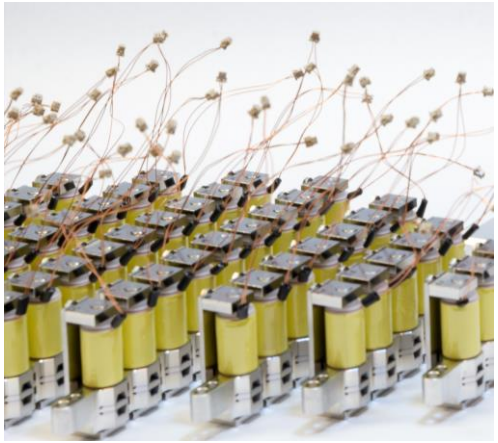
FIRST FULL DEFORMABLE MIRROR

- Proto #1 integrated end 2016
- Ø160mm, 57 actuators (18mm pitch)
- Actuator production by VDL
- Developed for ESA TRP study to explore use of AO in Space
- Recently completed test campaign for use in Adaptive Optics Correction Chain BB at Durham CfAI

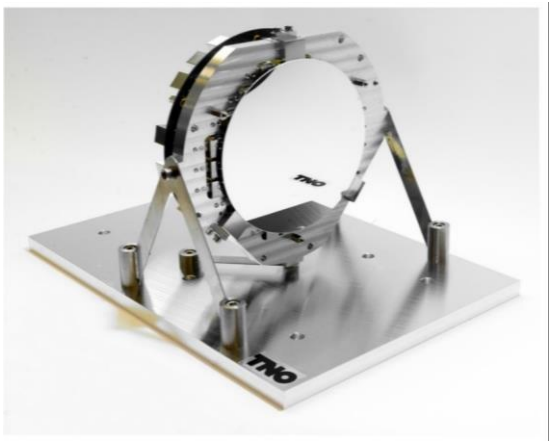
DM proto #1 specifications

Specifications	
Mirror diameter	Ø160mm
Number of actuators	57
Actuator pitch	18mm
Actuator stroke	40µm, Free stroke 10 µm, inter-actuator
Linearity	>99%
Max Power dissipation	<10mW per actuator
Best flat	<30 nm RMS
Actuator coupling	40%

Actuator set

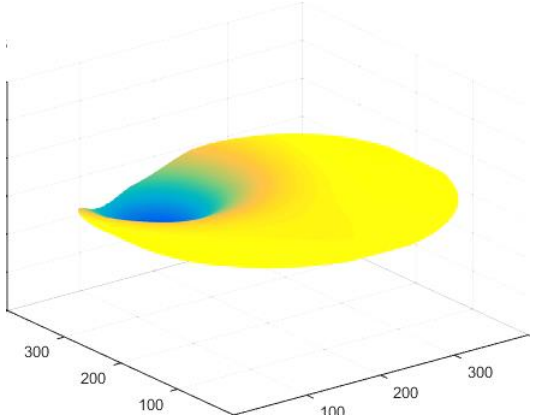


DM prototype



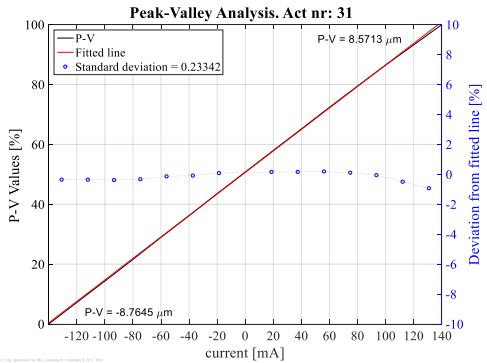
DM TEST RESULTS

- **99%** Linearity confirmed
- Best flat performance **32nm RMS**
  - limited by high initial unflatness of CotS fused silica wafer
- Power dissipation for initial flattening is **0.2 Watts** (total)



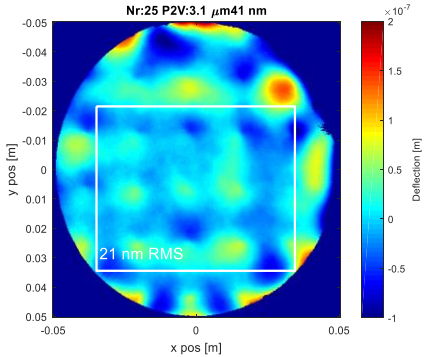
LINEARITY

Linearity > 99.5%

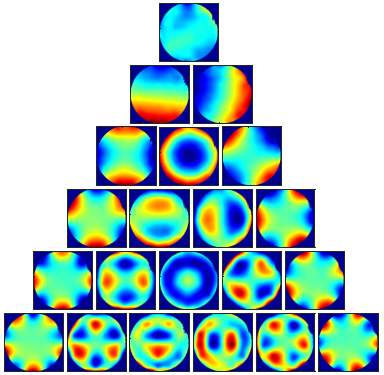


BEST FLAT

32 nm RMS (95% Apert.)

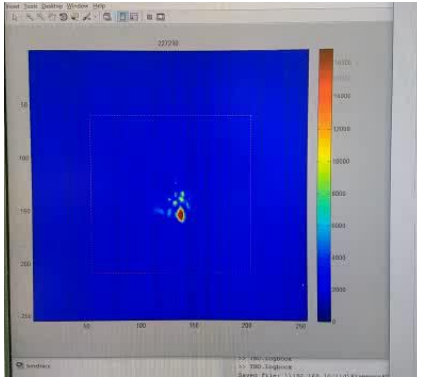


OPEN-LOOP CONTROL

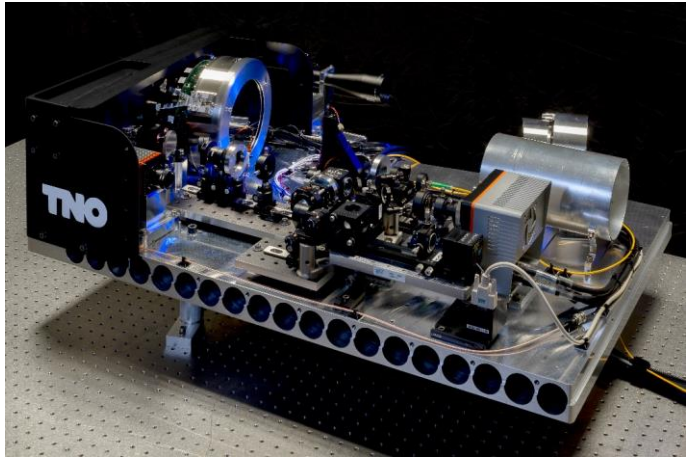


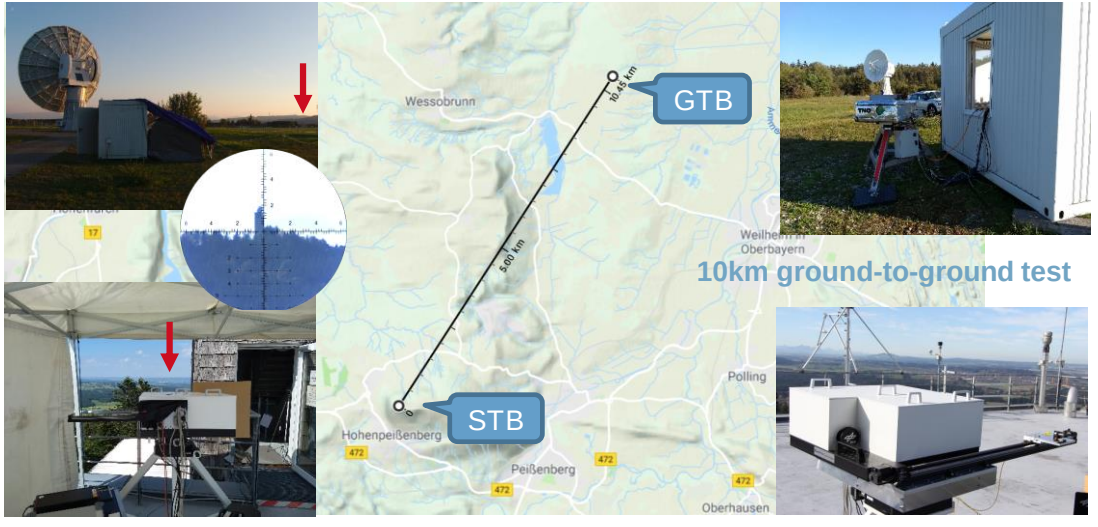
FIELD TEST - LASER COMMUNICATION

- Ground terminal bread-board developed for laser communication
- Goal: Verify performance gain with AO and sensitivity for Point-Ahead Angle
- Developed in ESA Scylight program in cooperation with DLR
- Uses a 57-actuator DM by TNO; manufactured by VDL



DM proto #2 (04/2018, satcom ground terminal)





10km ground-to-ground test

FSM FOR LASER-COMS

- Targeted for fast tip/tilt corrections and point-ahead angle in the space segment
- Utilizes the same actuator technology (different configuration)
- Prototype successfully tested (July-2017)

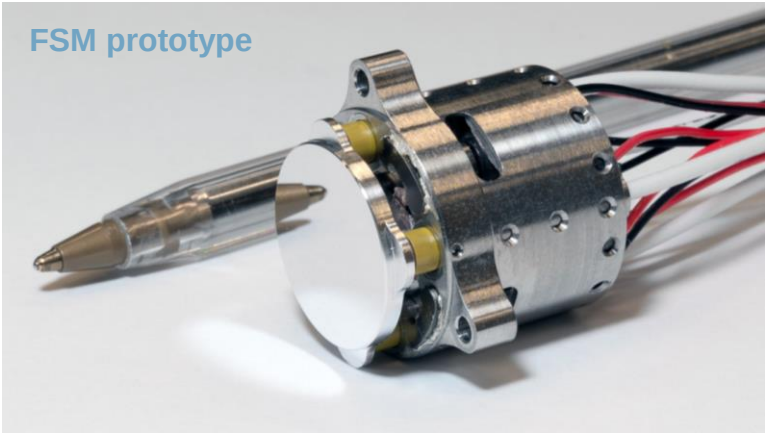
- Currently going through industrialization phase with industrial partner Demcon; several units sold already

DEMCON

FSM writing letters (40 Hz)

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

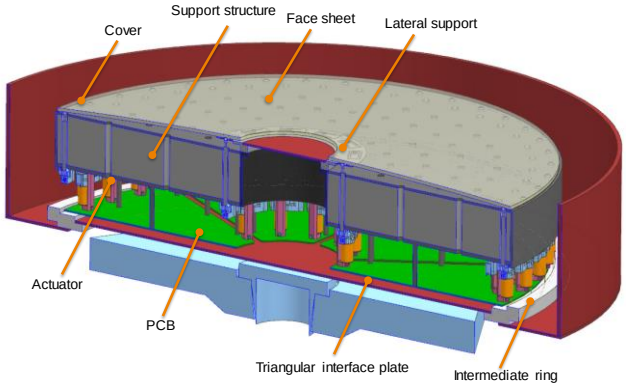
FSM prototype



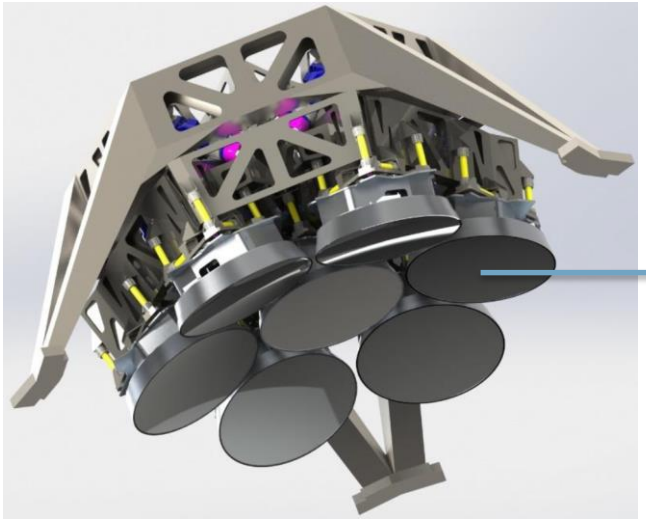
ASM TECHNOLOGY DEMONSTRATOR

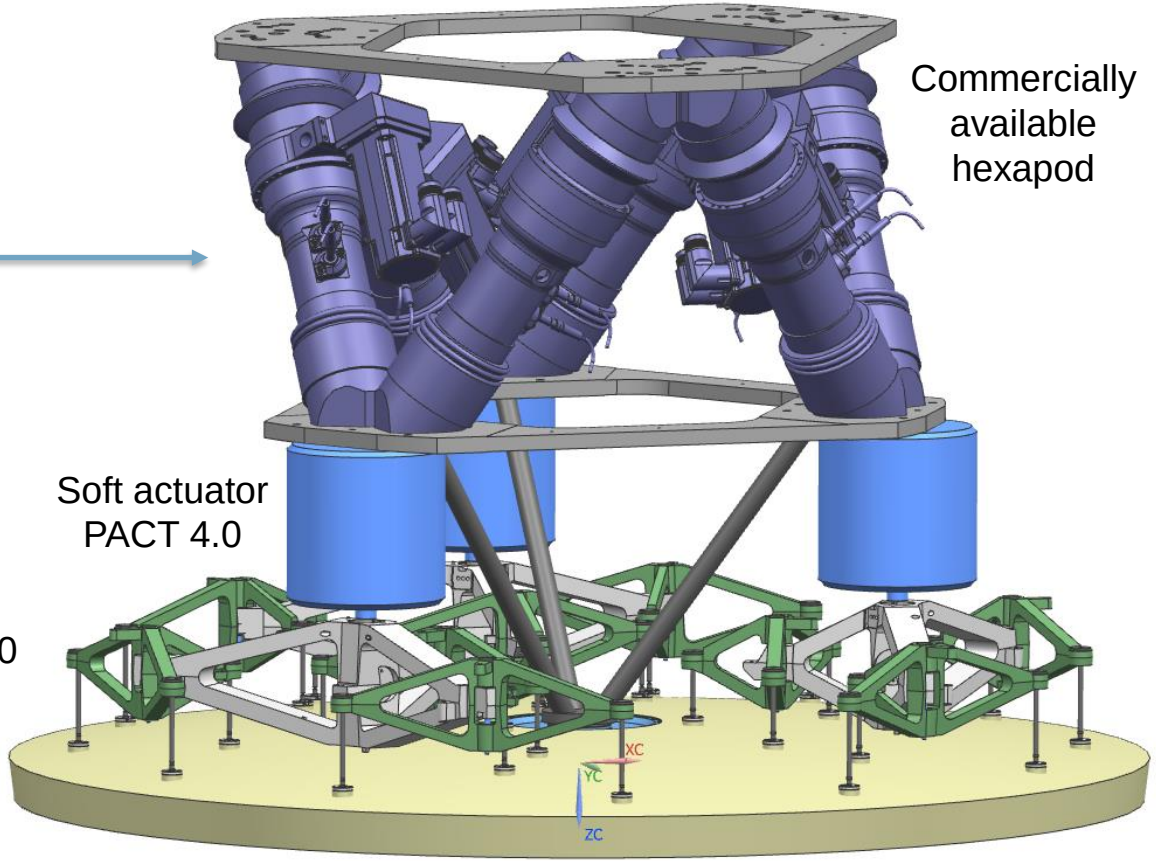
- Next step in astronomy: **UH-88** telescope on Mauna Kea
- Consortium partners:
  - University of Hawaii: advisor and virtual customer
  - TNO: development and performance testing
  - VDL ETG: actuators and integration
  - L3Harris: convex ULE face sheet
  - Hyperion: drive electronics
- Ongoing development, funded by partners & TKI grant
- Goal: on-sky demonstration of tech by end of 2020

Specifications	
Mirror diameter	Ø630mm (Convex)
Number of actuators	204
Actuator pitch	40mm, radial
Actuator stroke	35µm, Free stroke 4,5 µm, inter-actuator
Hysteresis	<1%
Actuator disipation	~2.3 W (204 actuator)
Total dissipation	~20W (control boards)
Overall mass	~50kg



DESIGN STUDY - GMT M2 SUPPORT STRUCTURE





Commercially available hexapod

Soft actuator PACT 4.0

Whiffle tree – M1SS 2.0

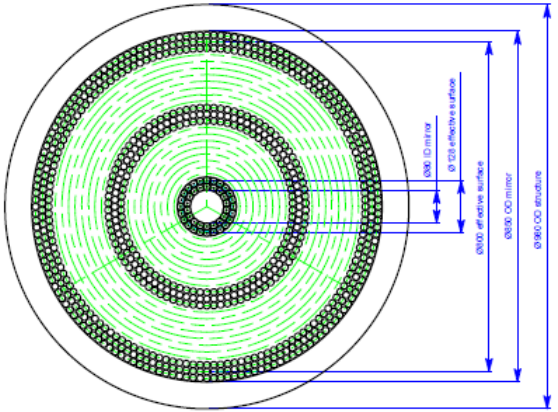
40mm thick solid mirror

-upgradeable to TNO/VDL ASM-

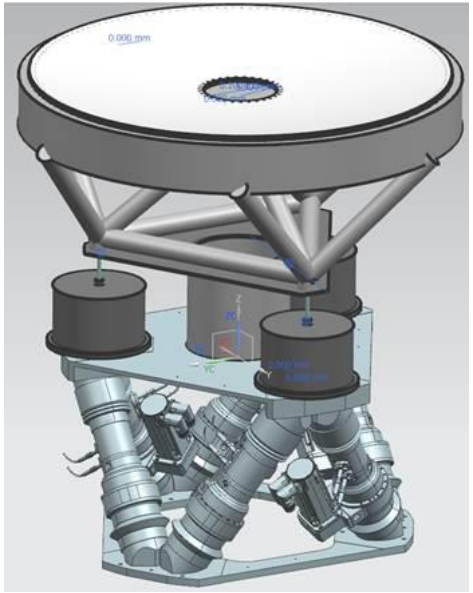
DESIGN STUDY: ASM FOR EUROPEAN SOLAR TELESCOPE

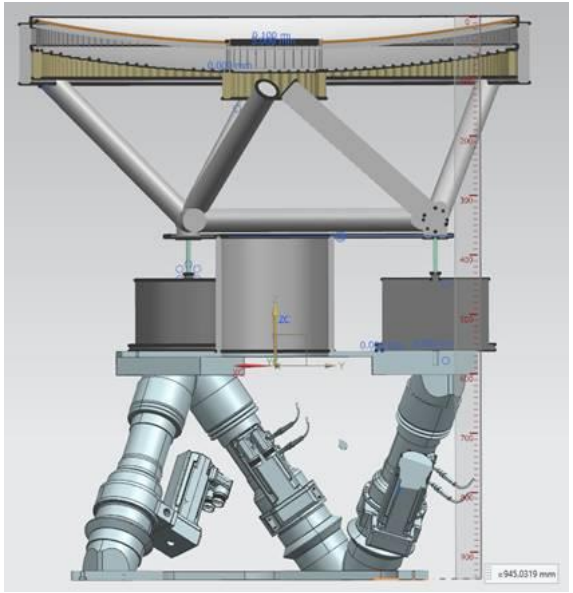
- ASM allows configuration to reduce from 13 → 6 mirrors
- High actuator density: 850mm diameter, >2000 actuators; 16mm pitch
- High heat-load (136Watts optical power, 20% absorption)

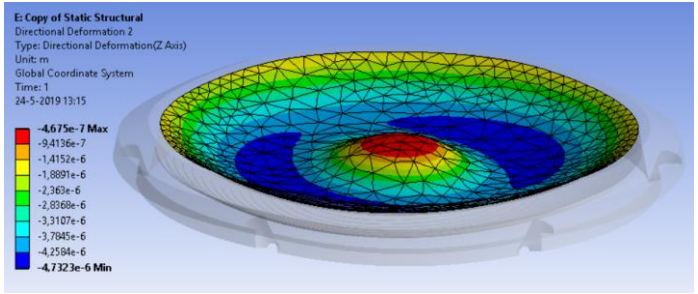
Our ASM concept uniquely allows for this density and operation under these loads



- All actuators Ø16mm.
- Ø128mm = estimation of inner edge of effective mirror surface.
- 18 additional actuators inside Ø128m for slope control at edge of effective surface.
- 156 additional actuators outside Ø800m for slope control at edge of effective surface.
- Including these 18 + 156 actuators a total of 1988 actuators are used.
- Ø980mm is nominal size excl. alignment range of e.g. +/-10mm (TBD).







CONCLUSION

- Development of key technologies & sharpening of skills in 1-off projects:
  - Support structures
  - Actuator technology
- Partially funded by ESO and ESA
- We now pro-actively target the market for scientific instrumentation


THANK YOU FOR YOUR ATTENTION
Take a look:
TNO.NL/ASTRONOMY
TNO innovation for life