Next generation of piezo deformable mirrors

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CILAS Deformable Mirror technologies

Monomorph Mirrors
MONO

Stack Array Mirrors
SAM

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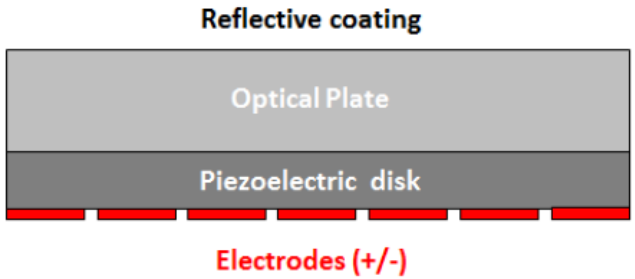
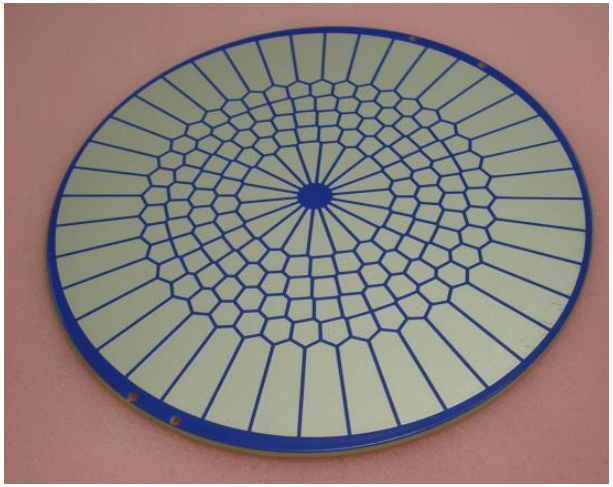
Monomorph mirrors- MONO

✓ Architecture and functional concept



- Architecture
  - One disk of piezoelectric ceramics + metallic coating (electrodes)
  - One disk of glass + reflective coating
- Functional concept
  - In-plane deformation of the piezoelectric disk due to transverse piezoelectric effect
  - Bending of the optical plate due to bi-metallic effect
- Simplicity of the technology:
  - No proximity electronics
  - No internal heat dissipations
  - No active thermal regulation
  - No actuators (only electrodes)
  - No mechanism or friction

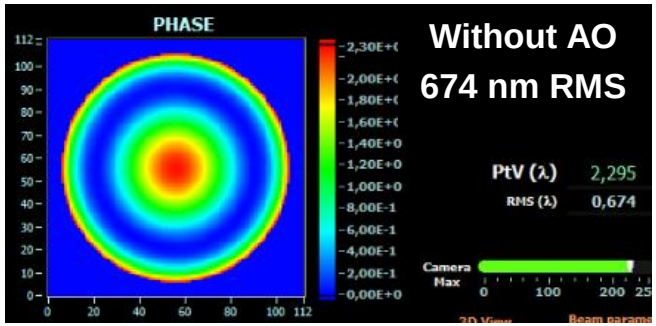
→ Light weight
→ High reliability

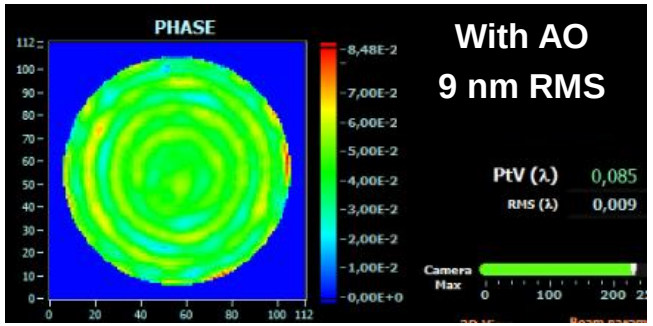


Monomorph mirrors- MONO

✓ Typical features

- Clear apertures: from 25 mm to 250 mm
- Number of electrodes: from 20 to 200
- High stroke: ±60 µm PtV wavefront
- No print-through
- Fast response time: ~ 100 µs
- Excellent optical quality: <10 nm RMS wavefront





✓ 20 years of heritage thanks to the first generation of bimorph DM

- Very Large Telescope: MACAO VLTI, SINFONI and CRIRES
- Subaru Telescope: AO36, AO188

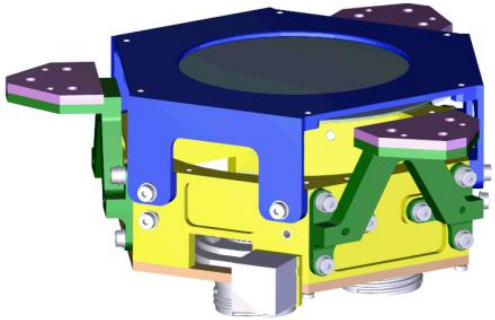
✓ 10 years of operating experience with unfailing reliability for solar and night astronomy

- Swedish Solar Telescope: MONO85
- China Academy of Science: MONO85, MONO63

Earth observation – a space qualified monomorph

- CILAS is developing a space-qualified monomorph DM to allow in-flight correction of the telescope distortions (thermal drifts, gravitation release…)

- Goal
  - To achieve TRL 6 on the DM technology
  - To be ready for Flight Models in 2017
- General features
  - Clear aperture ~ Ø 90 mm
  - Number of electrodes: 63
  - Mass < 2 kg
  - High correction efficiency
  - Non linearity ~ 1 %
- **Manufacturing of the Qualification Model**
  - Design according to ESA standards
  - Manufacturing with space-qualified components
  - Qualification tests on progress



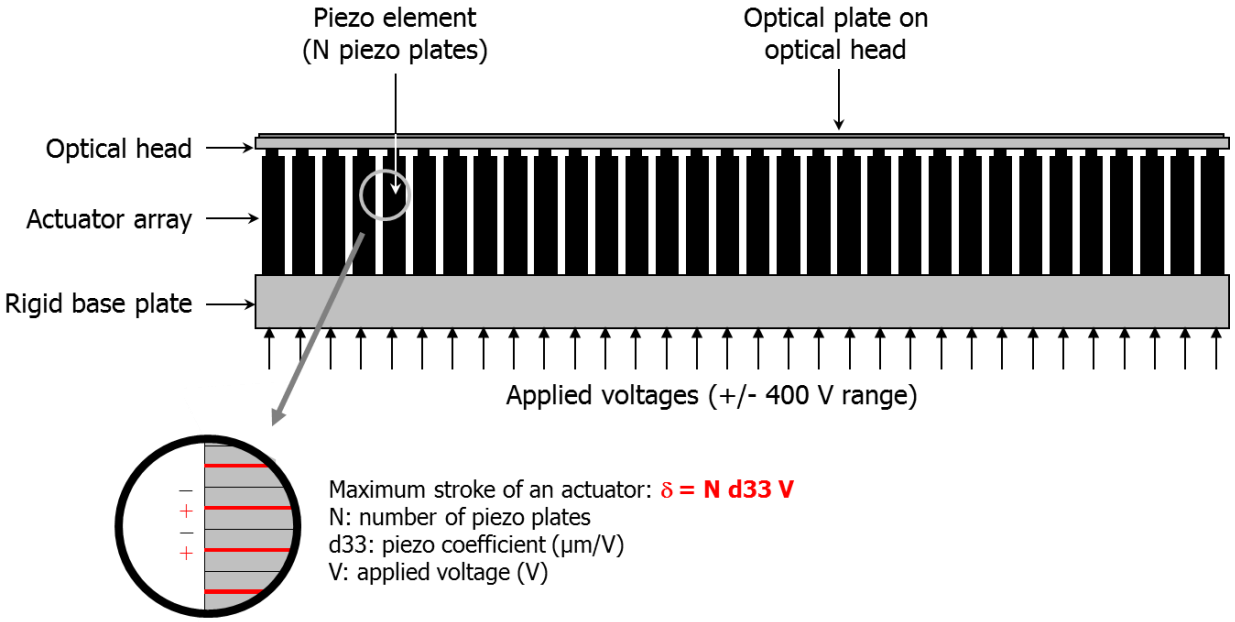
CILAS Deformable Mirror technologies

Monomorph Mirrors
MONO

Stack Array Mirrors
SAM

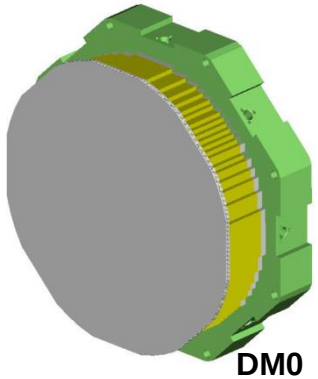
Stack-Array deformable Mirror - SAM

- Monolithic system based on piezoelectric actuators
- High order correction: pitch down to 3 mm, diameter up to 500 mm
- Large inter-actuator stroke: up to 4 µm
- High actuator resonance frequency (> 10 kHz)
- Very low non-linearity and hysteresis (< 5 %)
- High optical quality (< 10 nm RMS)
- Very low dependence to environment and temperature



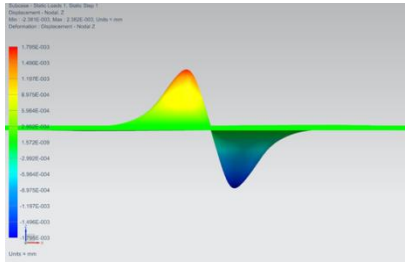
Design of two deformable mirrors for NFIRAOS

- **2 large deformable mirrors with operational temperature from -30°C to +20°C**
  - DM0: 3125 actuators, 63x63 array, 325 mm diameter
  - DM11: 4548 actuators, 76x76 array, 385 mm diameter



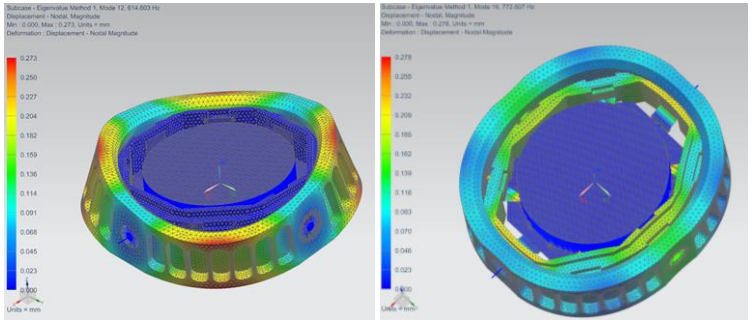
DM0

- **Specifications at ambient and -30°C**
  - Actuator pitch: 5 mm
  - Full stroke: > 10 µm PV
  - Inter-actuator stroke: > 2 µm
  - Optical quality: < 15 nm RMS
  - Actuator longitudinal resonance frequency: > 13 kHz



Influence function, push-pull

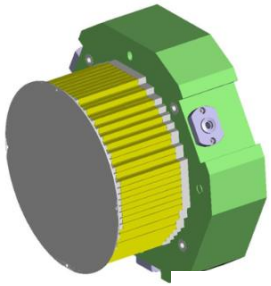
- **Design of the DMs**
  - Full design for DM0 and DM11
  - FEM for influence functions
  - FEM for thermomechanical behavior
  - Dynamic analysis of DM0 in the Tip Tilt Stage
    - Study done in partnership with NRC
  - Compliant with specifications

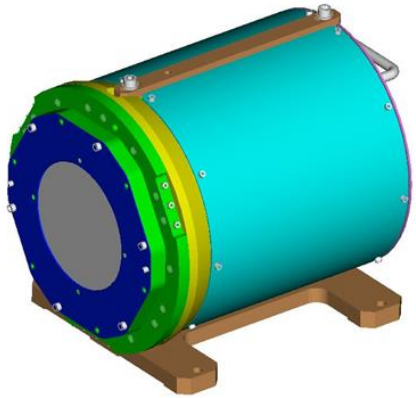


Examples of gimbal modes (DM0 in TTS)

Manufacturing of NFIRAOS DM prototype

- **A DM Prototype SAM616**
  - A real deformable mirror
  - 616 actuators, 28x28 array,
  - Actuator pitch: 5 mm
  - Operational aperture: 130 mm
  - Full specifications from -30°C to +20°C





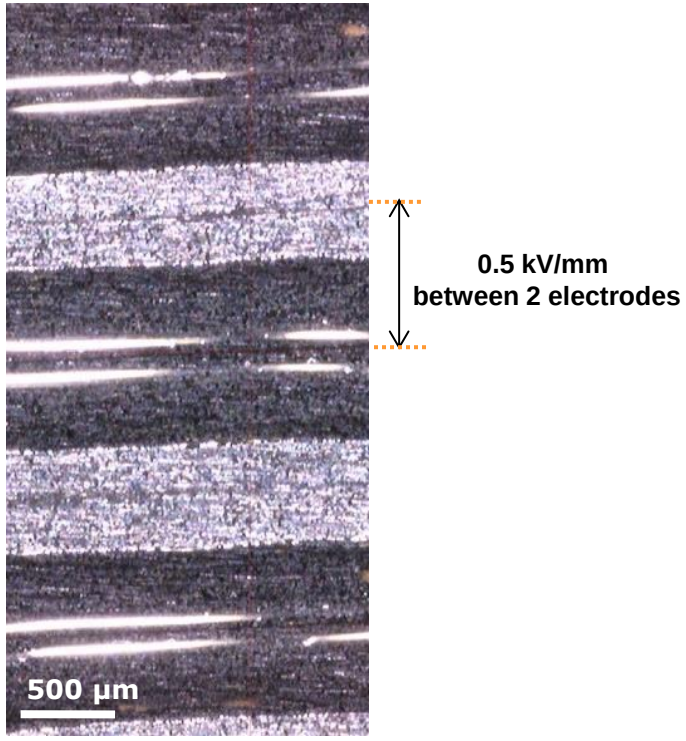
- **Goals**
  - To assemble the new generation of actuators
  - To validate an innovative optical head
  - To mitigate risks related to large DMs at -30°C

- **Progress**
  - Assembly is mostly completed
  - Then polishing and coating
  - Tests planed at ambient and at -30°C (by the end 2017)

New generation of piezo-electric actuators

- During the last years, CILAS has developed a new generation of actuators
- Based on new technologies focused on high reproducibility and high reliability
- More than 1000 actuators have been produced for TMT DM prototype

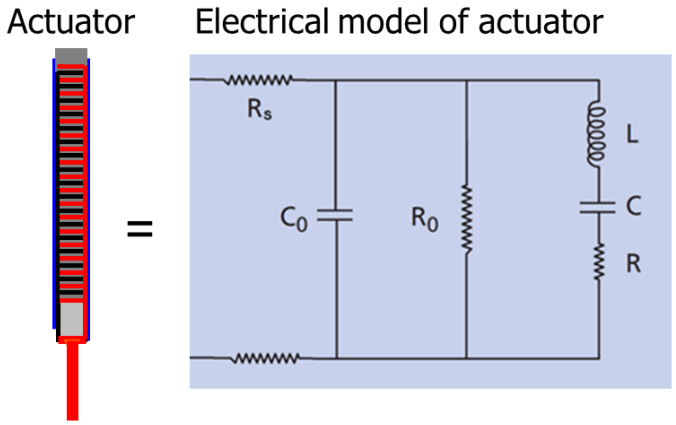
- Performances of the actuators
  - Free stroke: 15 µm PV mechanical
  - Free stroke uniformity: < 5% RMS
  - Non-linearity and hysteresis: < 3% PV
  - Actuator longitudinal resonance frequency: > 13 kHz
  - Large range of operational temperature: down to -30°C



Picture of a stack actuator during manufacturing (microscope X60)

Systematic tests on all actuators

- High continuous voltage test
  - Scope: to drive the actuators under relative high voltage to check their dielectric withstand
- Burn in test
  - Scope: to drive the actuators under hard conditions (temperature, humidity) during a reduced period
- Electrical test in operational conditions
  - Scope: to drive the actuators under electrical conditions of operation in order to detect possible behavior modification
- Capacitance
  - Specification: < 5 % RMS
  - Obtained value: 1% RMS
- Contacting resistance
  - Maximum value Rs < 10 Ω



➡ **Possible defects or weaknesses can be detected**
-> selection of actuators to be assembled on DM

Yield : more than 90% manufactured actuators = reliable actuators

Lifetime and reliability of the actuators (1/2)

❑ Mechanical fatigue

- Test performed at 26 kHz and 15 % of the maximum stroke
- 100 times the maximum current in operation
- 35 billion cycles have been performed without any damage
- 20 billion cycles represent about 20 years of operation on telescope

❑ Electrical breakdown voltage

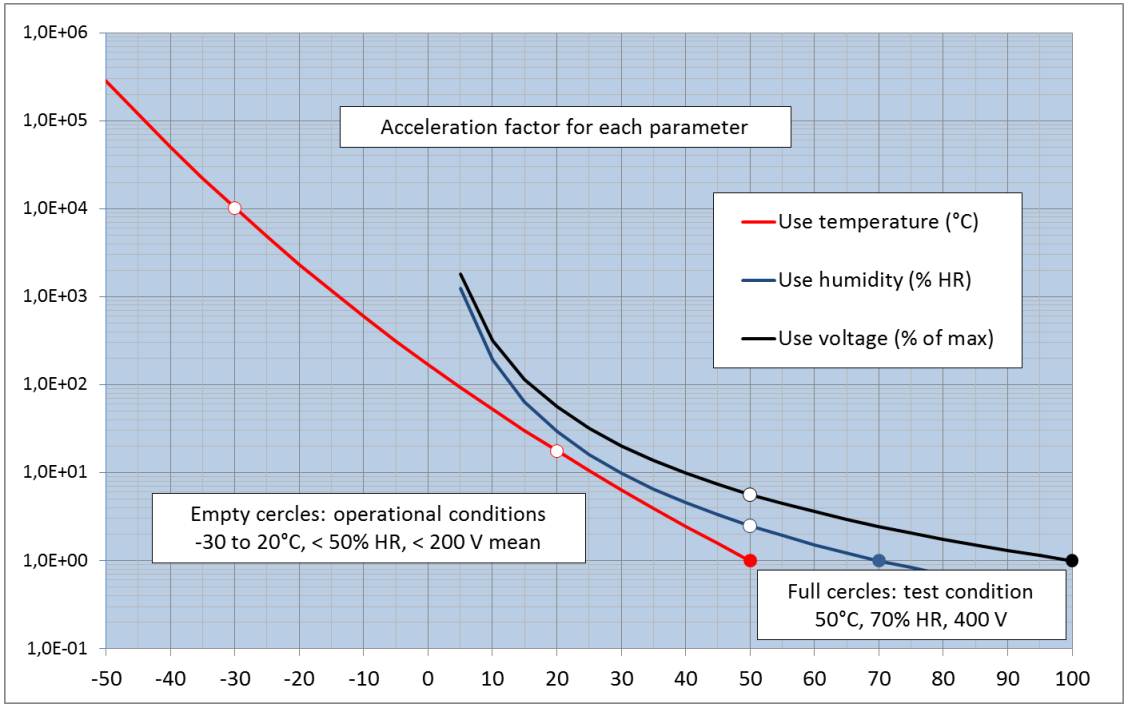
- The electrical field is lower than other piezo technologies (0,5kV/mm)
- Test performed with increasing voltage up to short-circuit

	Breakdown voltage
Goal: (2 x U) + 1000 V (based on high voltage standard - HiPot)	1800 V
Minimum voltage	3670 V
Average voltage	3900 V
RMS	7%

➡ **Large mechanical and electrical safety margin**

Lifetime and reliability of the actuators (2/2)

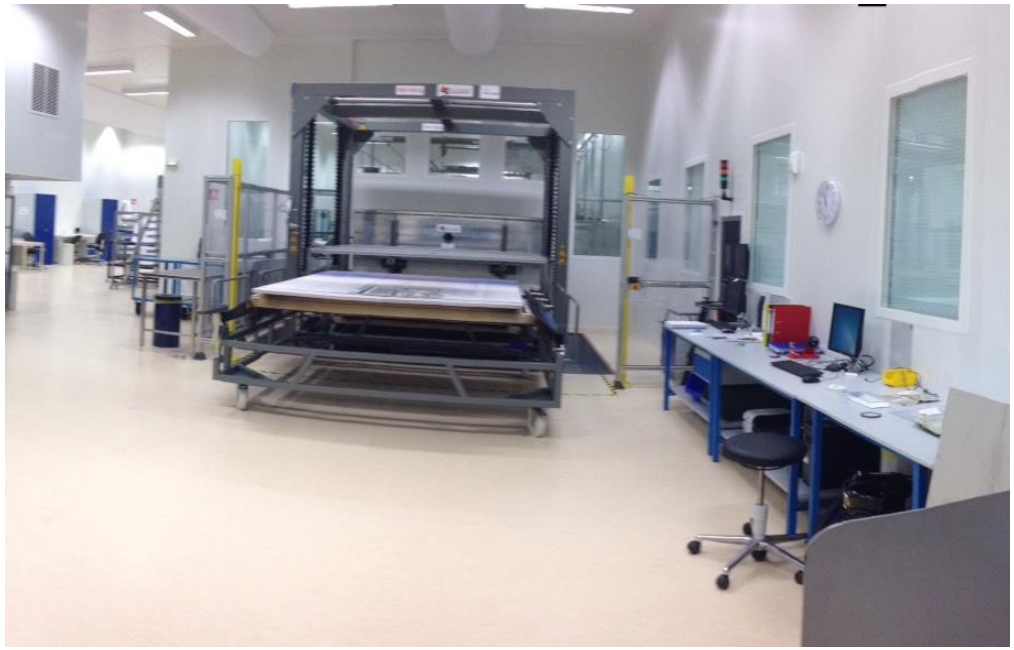
- **Accelerated Life Test (ALT)**
  - Goal : to validate the operational lifetime of the actuators
  - Accelerated ageing test at 50°C, 70% HR, 400V DC during 100 hours
  - Dozens of actuators successfully tested
  - **Result: operational lifetime of actuators > 20 years**



Coating development

- New coating developed by CILAS for astronomy
  - Enhanced protected silver coated by magnetron sputtering in the large 2-meter PACA2M machine

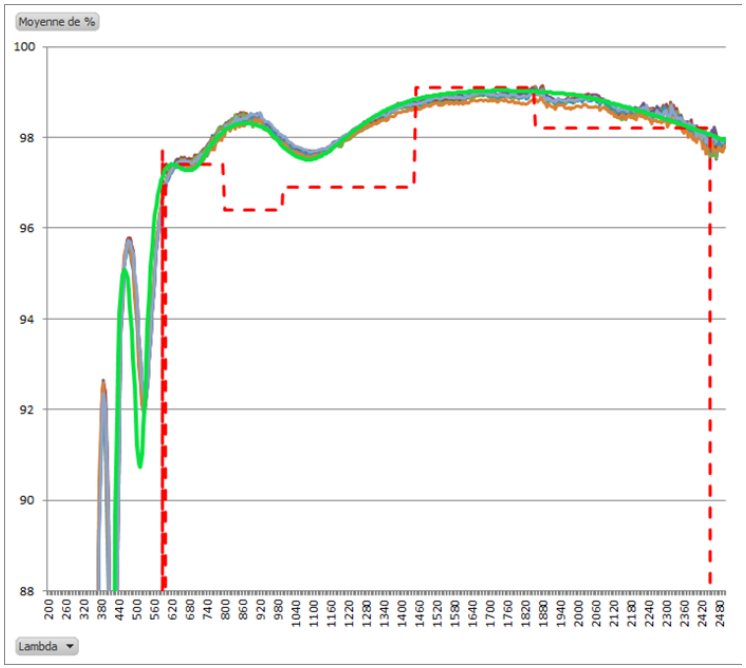
Al coating for the OAJ observatory
mirror diameter 1,25m
weight 320kg



The 2 meter x 2 meter PACA2M sputtering machine in the clean room

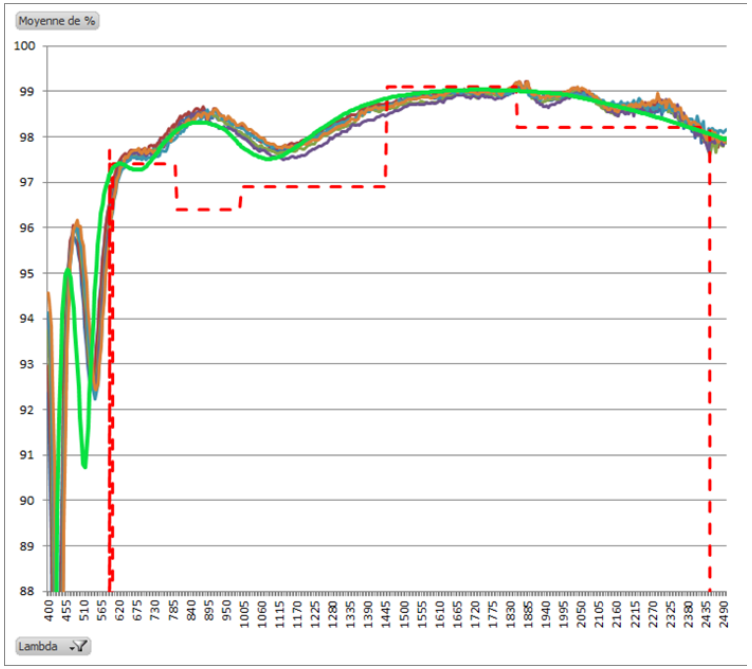
Coating development

- New coating developed by CILAS for astronomy
  - Enhanced protected silver coated by magnetron sputtering in the large 2-meter machine
  - All performances achieved: reflectance, homogeneity, adhesion, thermal cycling, ageing.



Reflectance homogeneity Ø400mm

(Theoritical curve in green)



Reflectance before and after ageing test

(Theoritical curve in green)

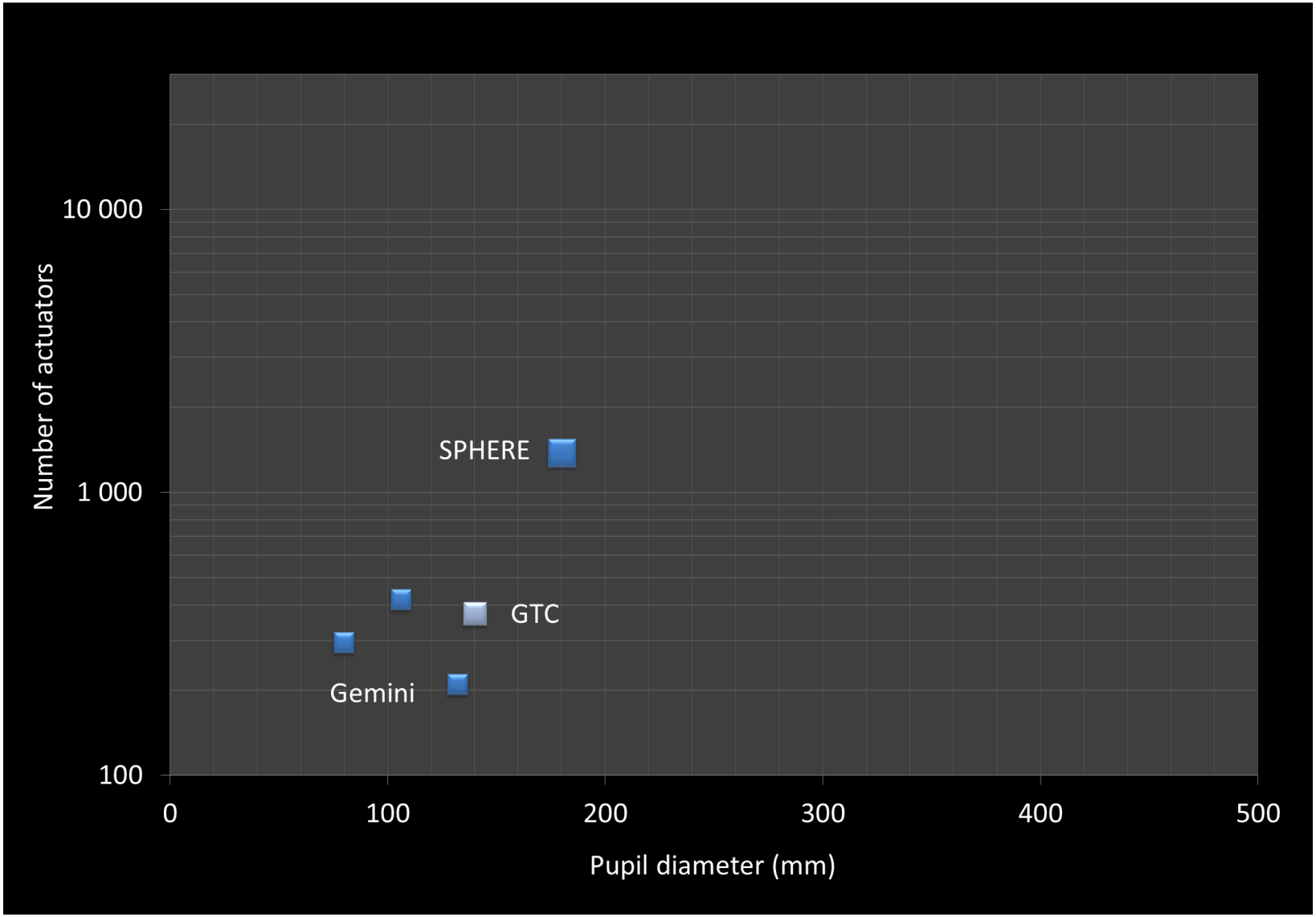
Deformable mirrors for MAORY

- Multi-conjugate Adaptive Optics RelaY (MAORY) is the adaptive optics module for the European Extremely Large Telescope (E-ELT)

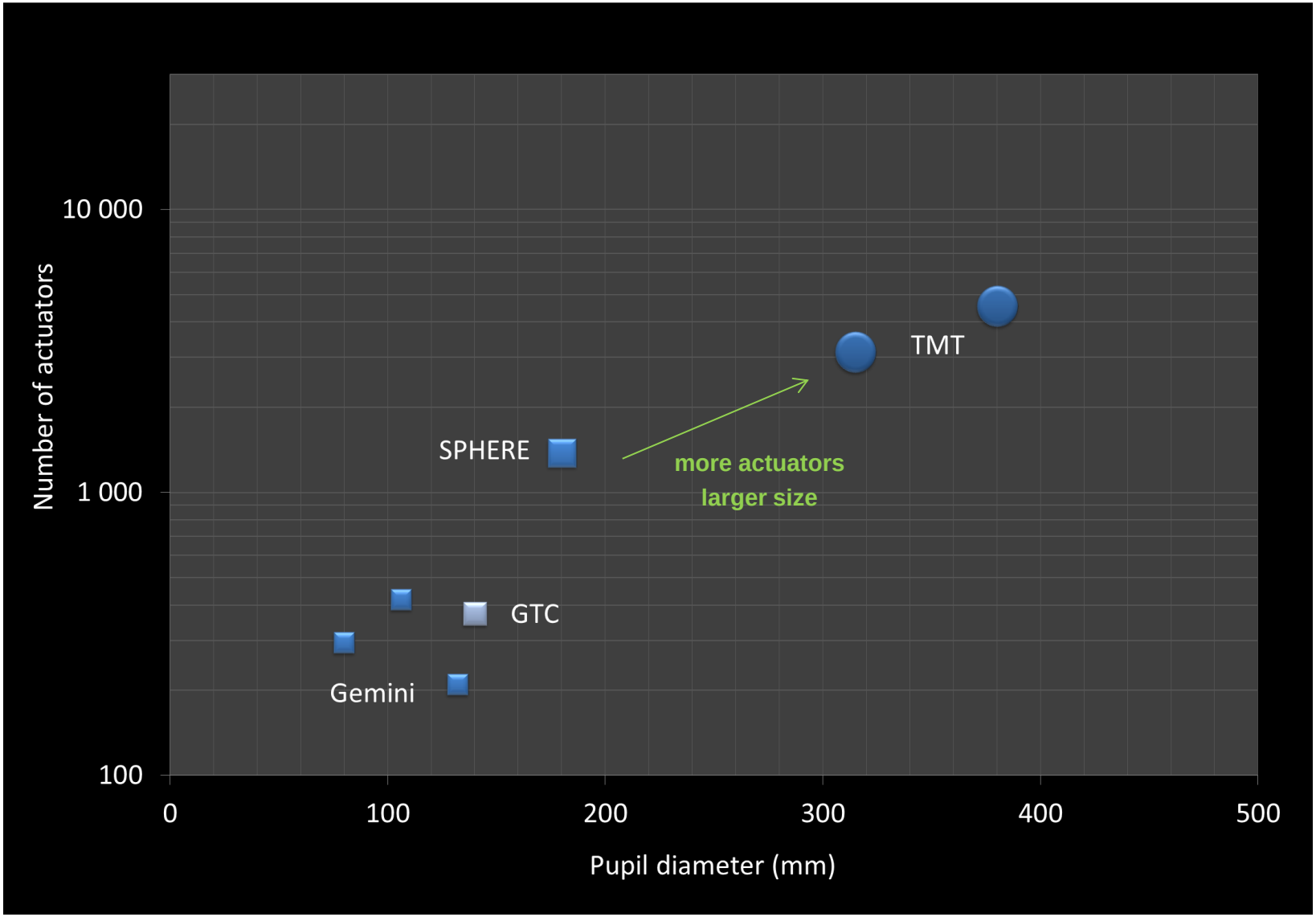
- 2 identical multi-conjugate deformable mirrors
  - 400 to 500 mm diameter
  - 1000 to 2000 actuators
  - Curved optical surface (aspherical concave or convex) -> innovative optical head
  - Actuator pitch close to 10 mm
  - Operational temperature: -5°C to 25°C
  - New generation of actuators
  - Negligible thermal dissipation
  - Optimized mass and space envelop

- **Mirror performances at ambient and -5°C:**
  - Full stroke: > 7 µm PV
  - Inter-actuator stroke: > 2 µm
  - Optical quality: < 20 nm RMS
  - Actuator resonance frequency: > 10 kHz

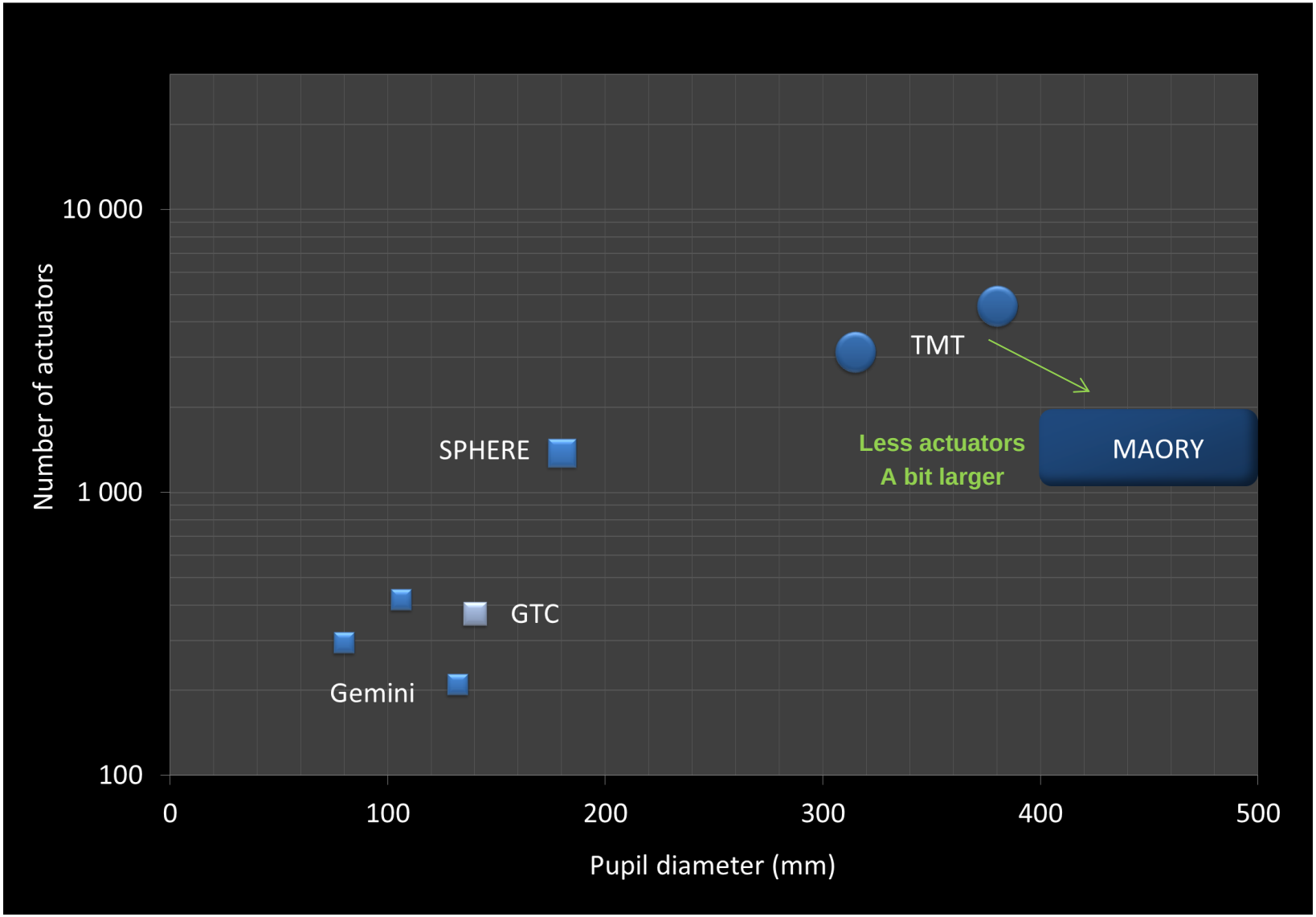
Current generation of Stack Array Mirrors



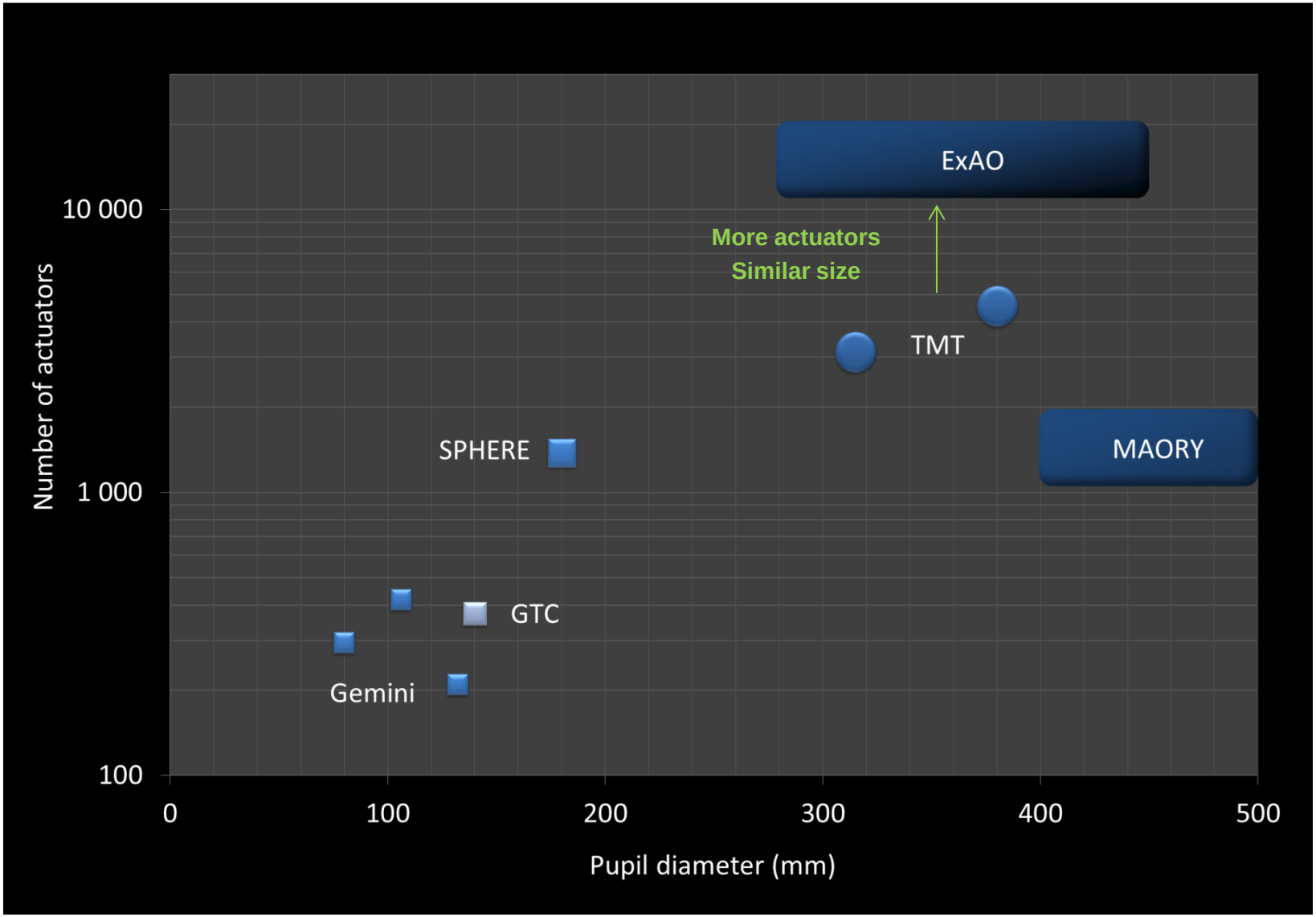
Next generation of Stack Array Mirrors



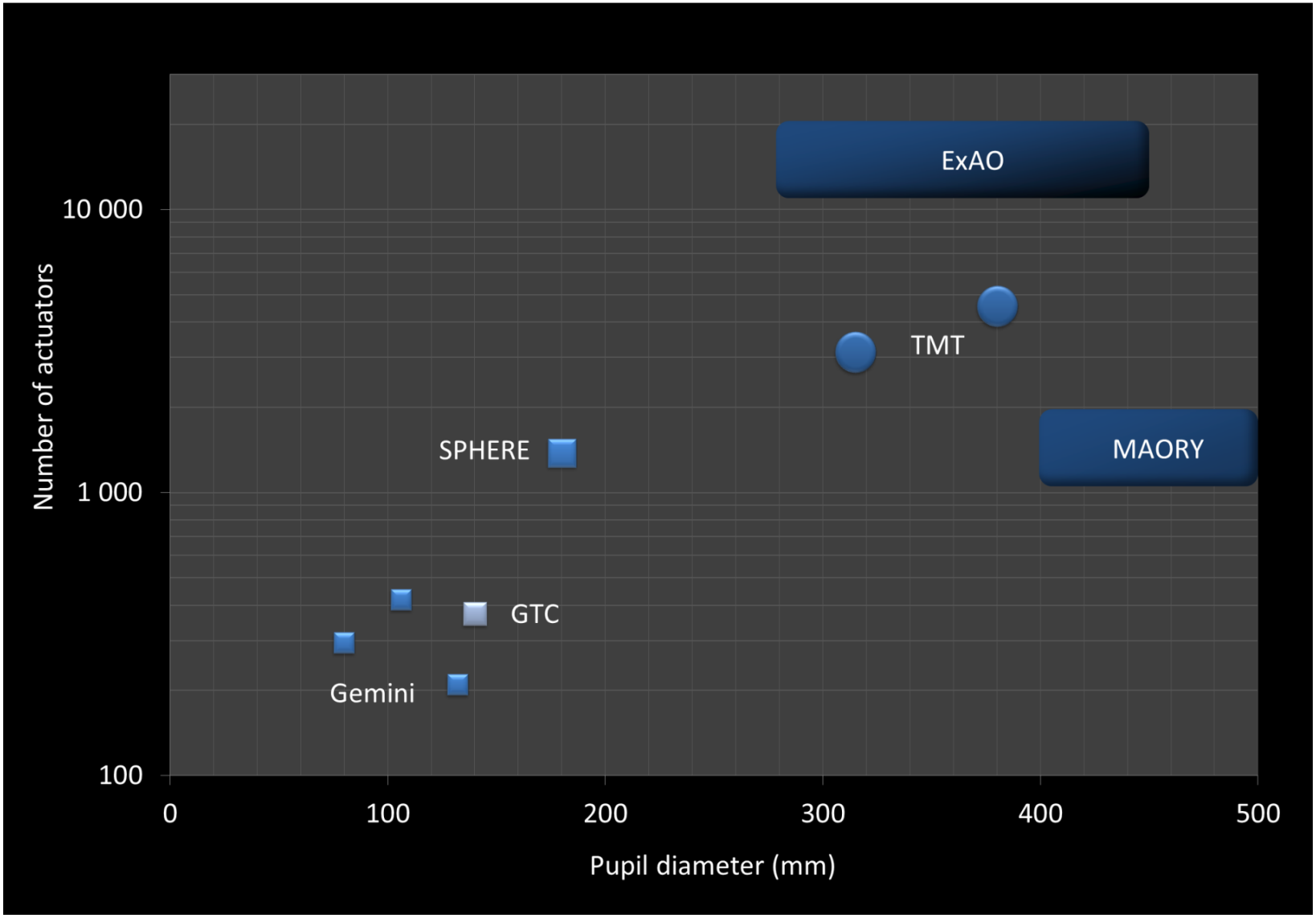
Next generation of Stack Array Mirrors



Next generation of Stack Array Mirrors



Next generation of Stack Array Mirrors



Thirty Meter Telescope, credit: TMT.
European-Extremely Large Telescope, credit: ESO.
Orion bullets, by GeMs, credit: Gemini Observatory/AURA, :
HR 4796A star by SPHERE, instrument credit: ESO,

Thank you for your attention