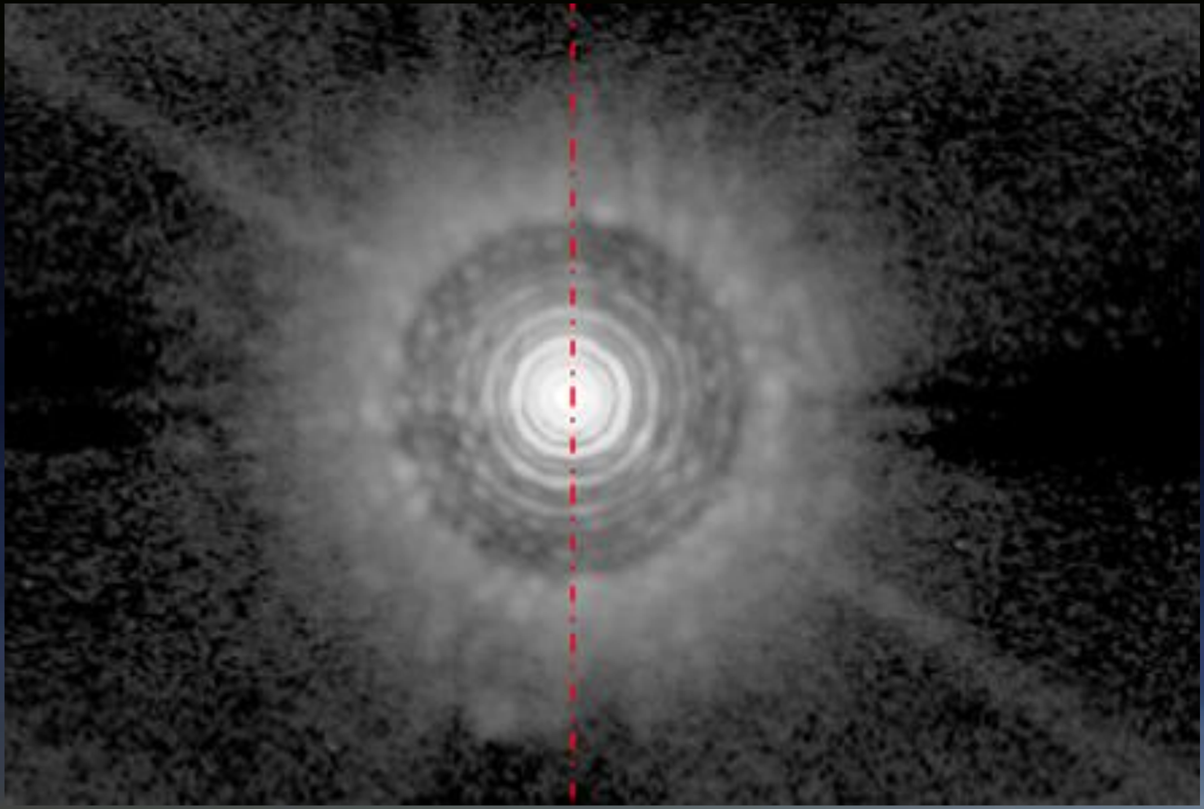


Adaptive Optics:

from astronomers to amateurs, where we stay and were we go.

CEDIC 2013 @ *Ars Electronica Center*, Linz, Austria

Paolo Lazzarini

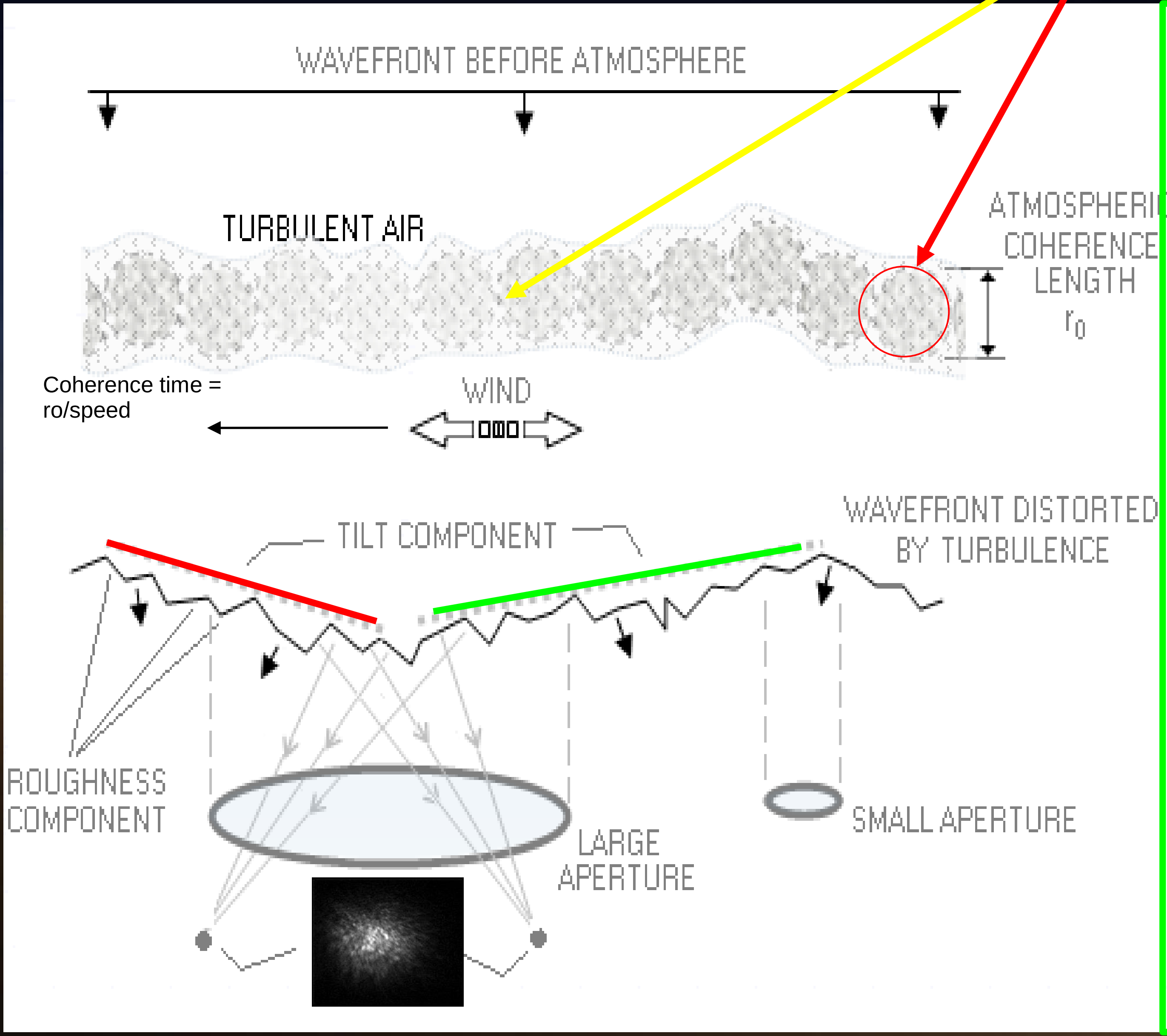
Our atmosphere

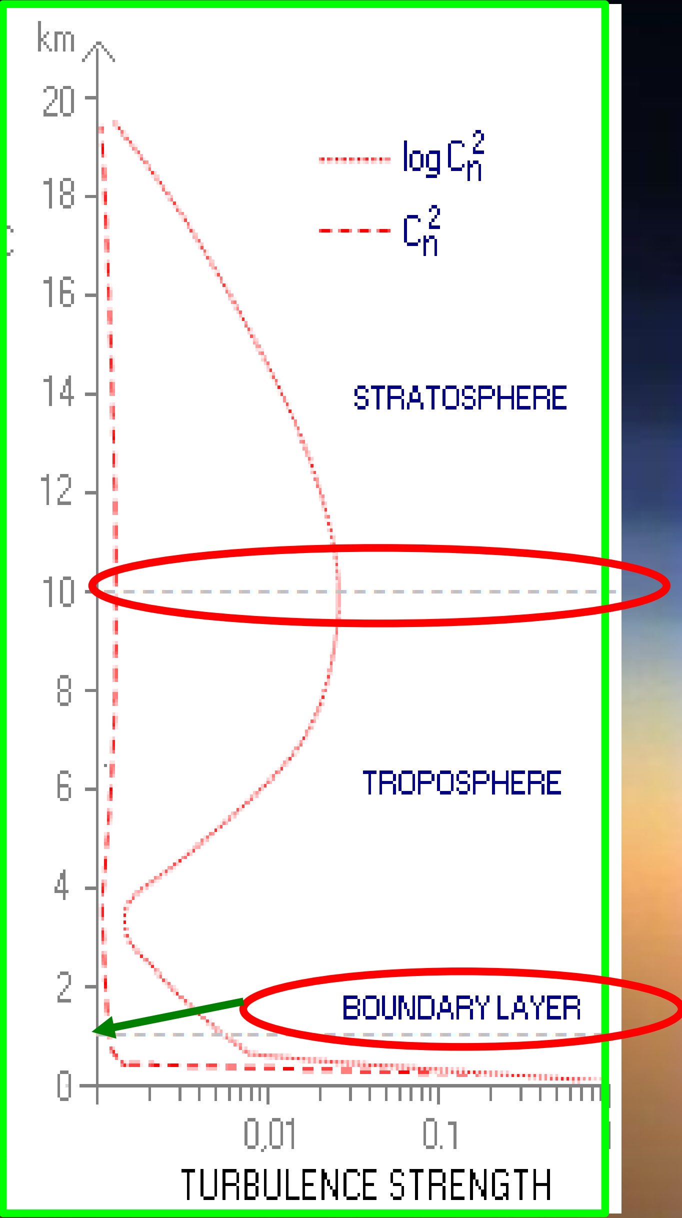
Light waves travel nearly uncorrupted for <u>million of years</u> and then, in the last 50 μ sec they are almost destroyed by a thin layer of atmosphere, this is really a pity.

This atmospheric perturbation is, in the end, what we call SEEING...

What's the SEEING

http://www.telescope-optics.net/induced.htm

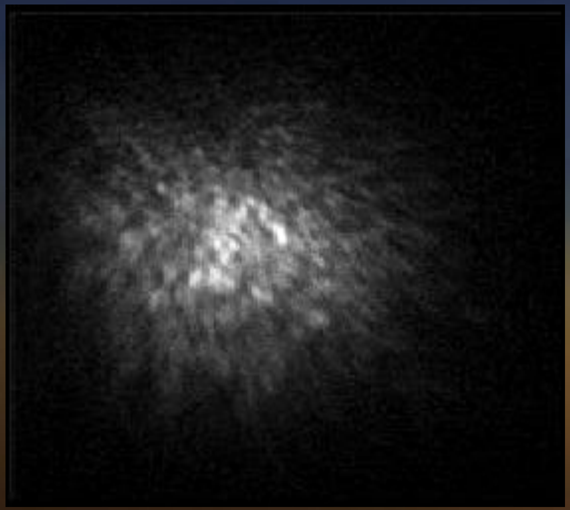




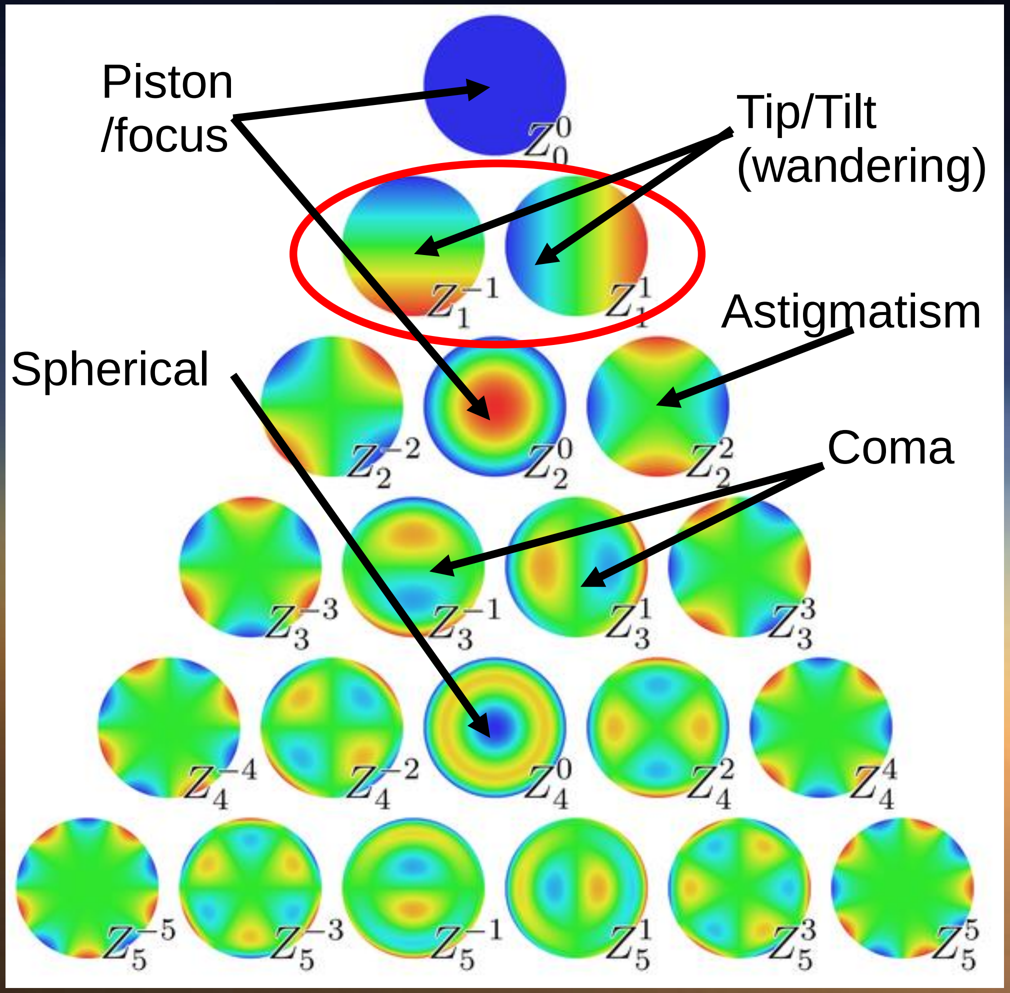
SEEING & Apparent CAOS

“Apparent CAOS” = low + high order distorsions of the wavefront

These distorsions can be identified and decomposed in elementary modes



$= \Sigma$



Base example: Zernike polynomials

When seeing starts disturbing ???

SEEING strongly affects telescope performances, even at best astronomical sites and also for SMALL telescopes:

Let's talk of median seeing condition.

*Hawaii/MK ~ 0,43 asec

*Antartica ~ 0,27 asec

0,1 asec at best, 10% of nights

Telescope diameter (mm)	Th. Resolving Power (arcsec)
100	1,16
200	0,58
300	0,39
400	0,29
500	0,23
600	0,19
700	0,17
800	0,14
900	0,13
1000	0,12

Limit diameter at BEST sites (for diffraction limited performances)

Optical resolution of 1 meter class telescope is comparable the best seeing on earth (ANTARTICA, 10% of the nights only)

HUGE telescopes NEED Adaptive Optics

What this mean practically ?

1) MEASURE the “Caos” in real time (FASTER than the Caos itself)

⇩

2) COMPUTE the necessary counter measure (quickly)

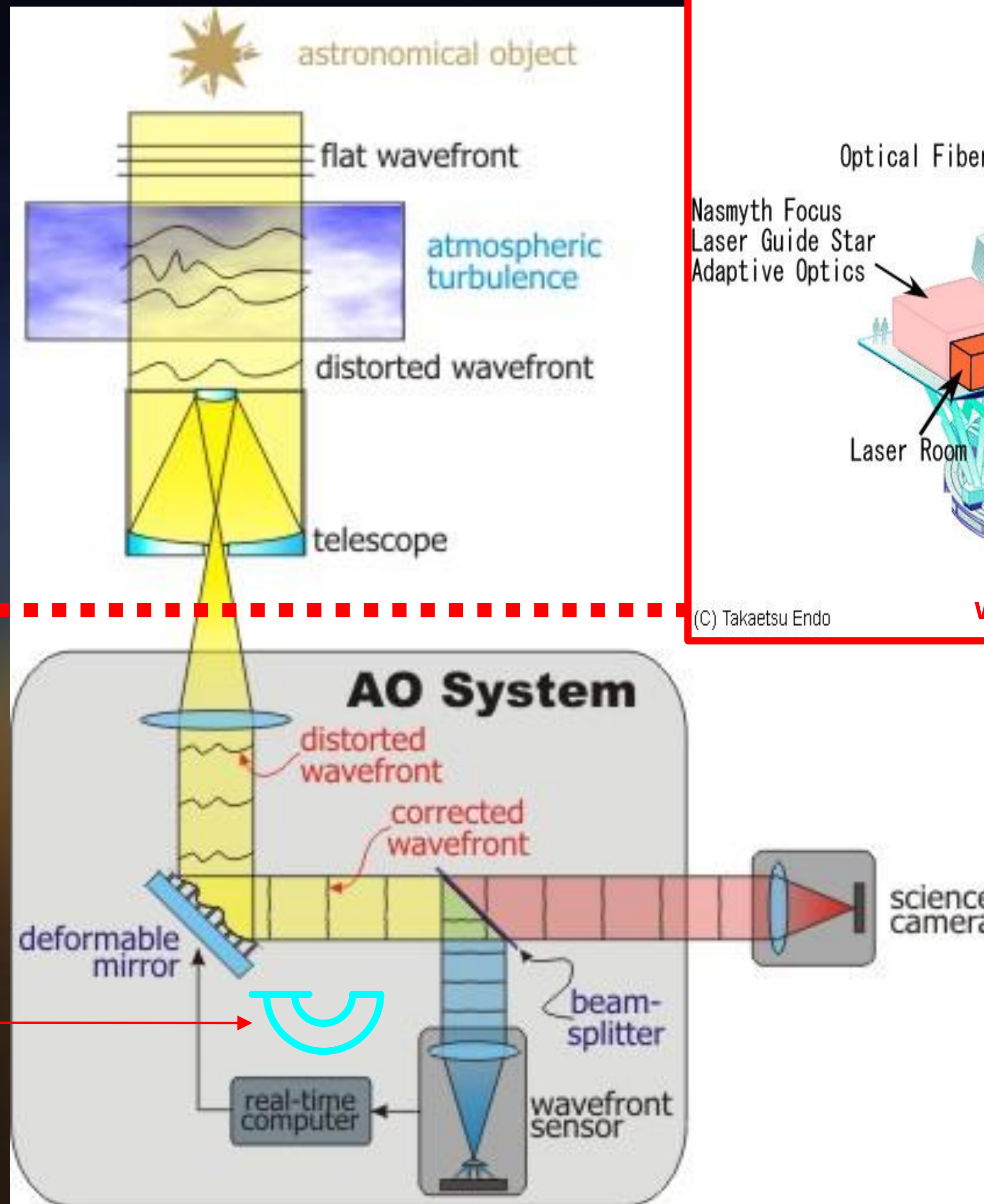
⇩

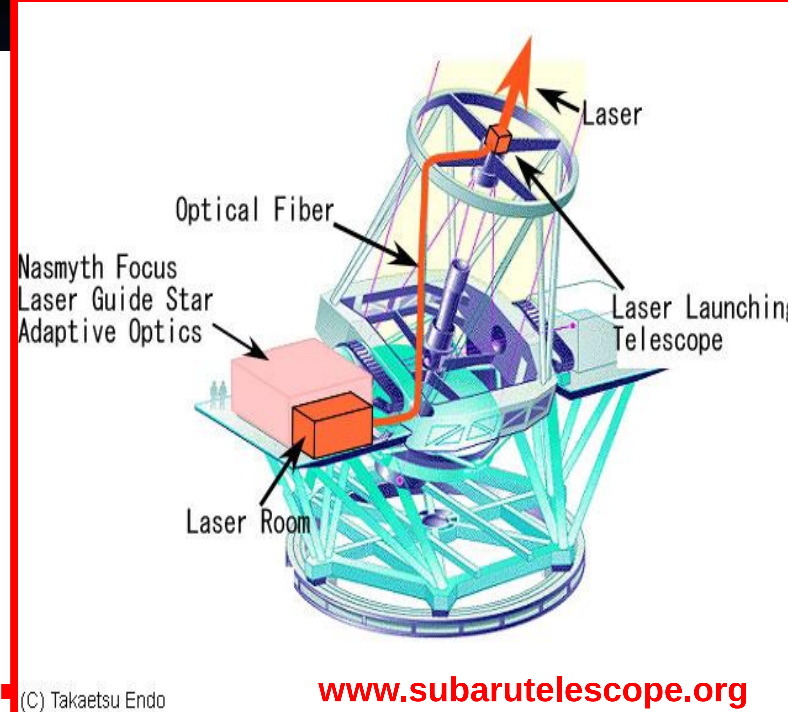
3) APPLY this counter-measure... quickly (typically with a deformable mirror)

(AO was first envisioned by Horace W. Babcock in 1953) !!!

A "CLASSIC" PROFESSIONAL SYSTEM...

In conventional AO systems, the deformable mirror is part of the scientific instrument

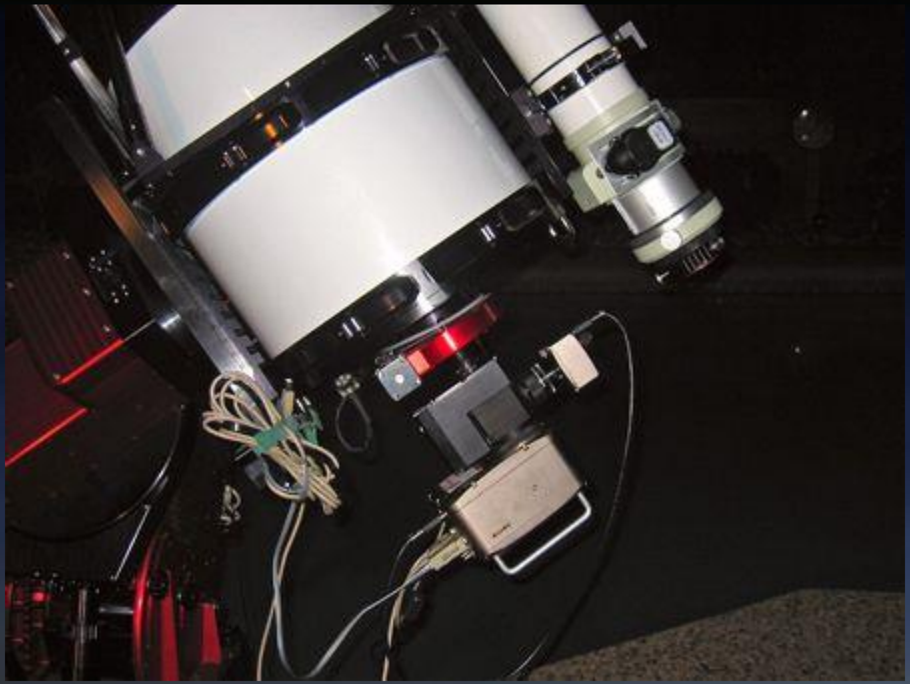




www.subarutelescope.org

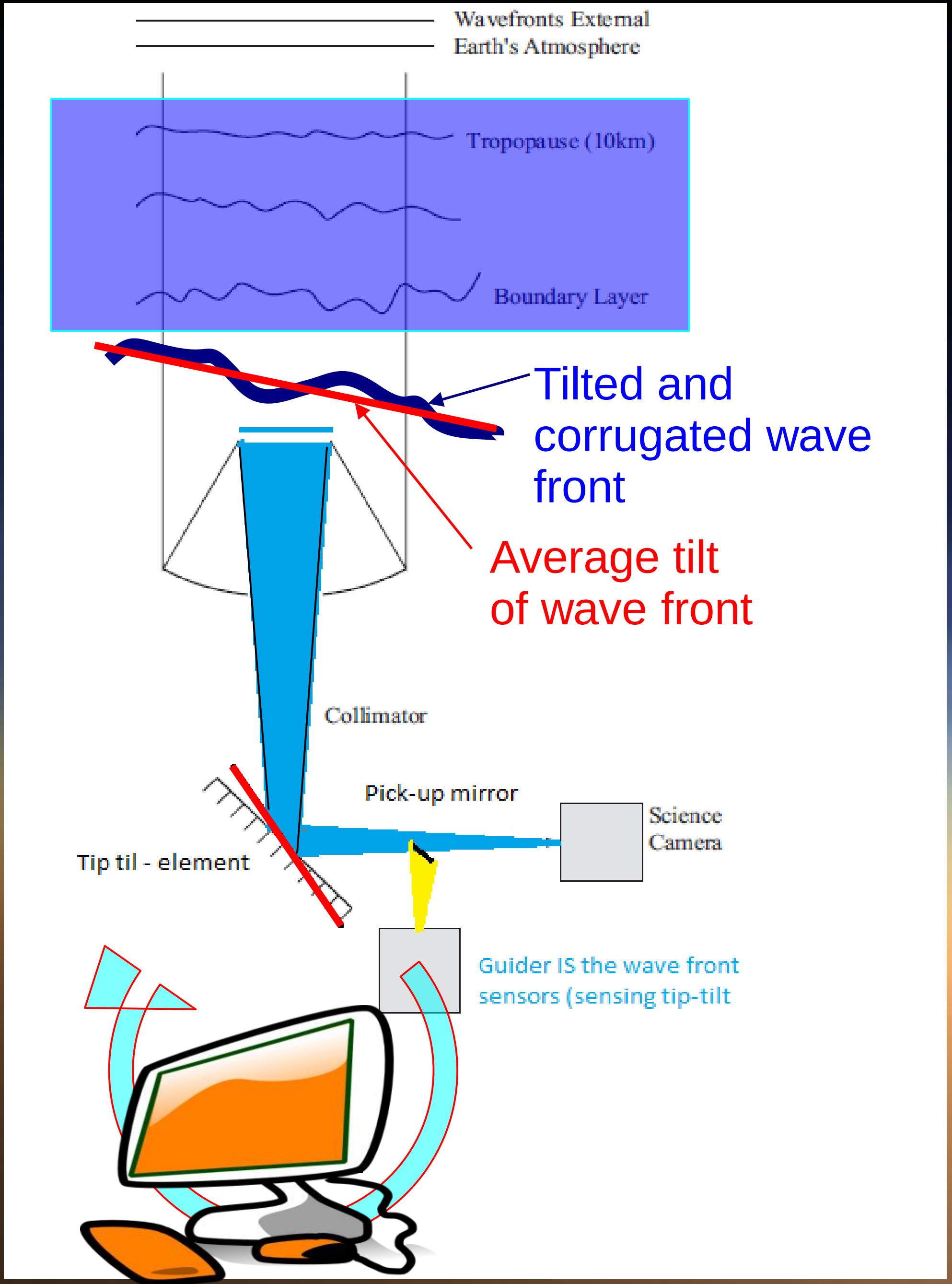
Feedback loop: next cycle corrects the (small) errors of
the last cycle

Amateur approach to “adaptive optics”

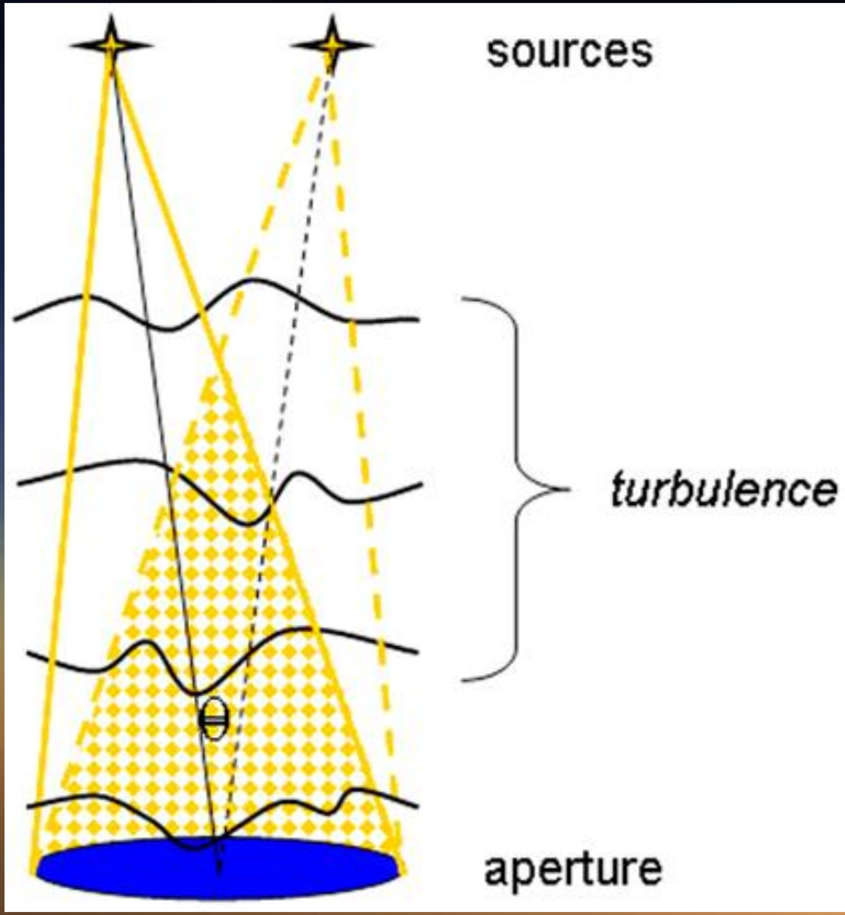


In AMATEUR “AO systems” the core element is a simple mirror (or lens). It is used as
- Fast Guiding (or field stabilization)
- Partial (*) AO compensation of average atmospheric tip-tilt

(*) TIP-TILP Turbolence is often non-coherent (non uniform) over the FoV of typical amateur setups



The bad news !
The isoplanatic angle
IS SMALL !!!



Turbolence is not the same all across your Field of View.
It remains consistent within a solid angle called Isoplanatic Angle.

As the your FoV deviates from your reference star, the correction you apply is no longer valid since the turbolence path from starts to the telescope is different.

The bad news !
The isoplanatic angle :-(

Real Case: Paranal - Chile, Year 2000

Source ESO

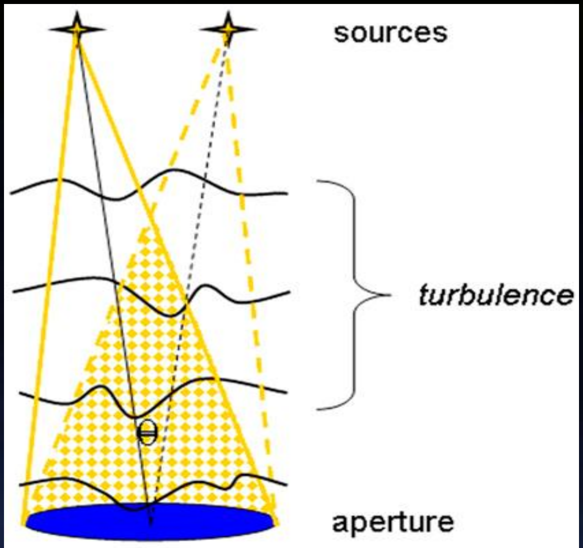


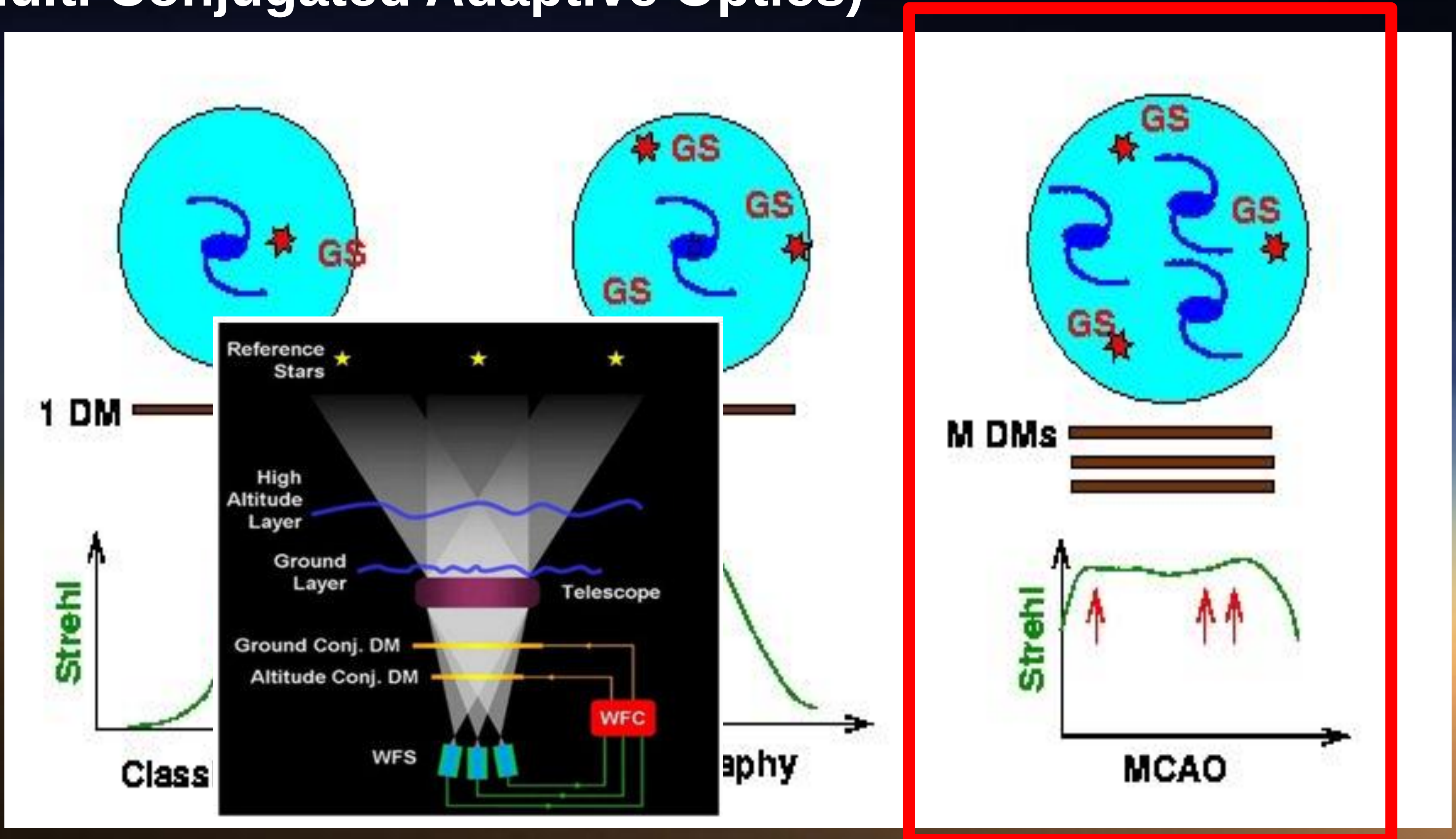
Table 2. Summary of AO related observing conditions at Paranal during 2000, for observation at 0.5 μm, at zenith, averaged over 10 mn. Data is not corrected for a finite outer scale of the turbulence.

Parameter	best 5%	best 20%	50%	mean
Seeing, arcsec	0.43	0.56	0.75	0.86
200mb Wind, m/s	12	19	29	32
τ_0, ms	8.5	5.8	3.6	3.9
θ_0, arcsec	4.1	3.3	2.6	2.6

Seems scaring ….. is this all we can do with AO? NO !!!

Extending the FoV ….

Using more stars, more WFSs, more DMs – MCAO (Multi Conjugated Adaptive Optics)



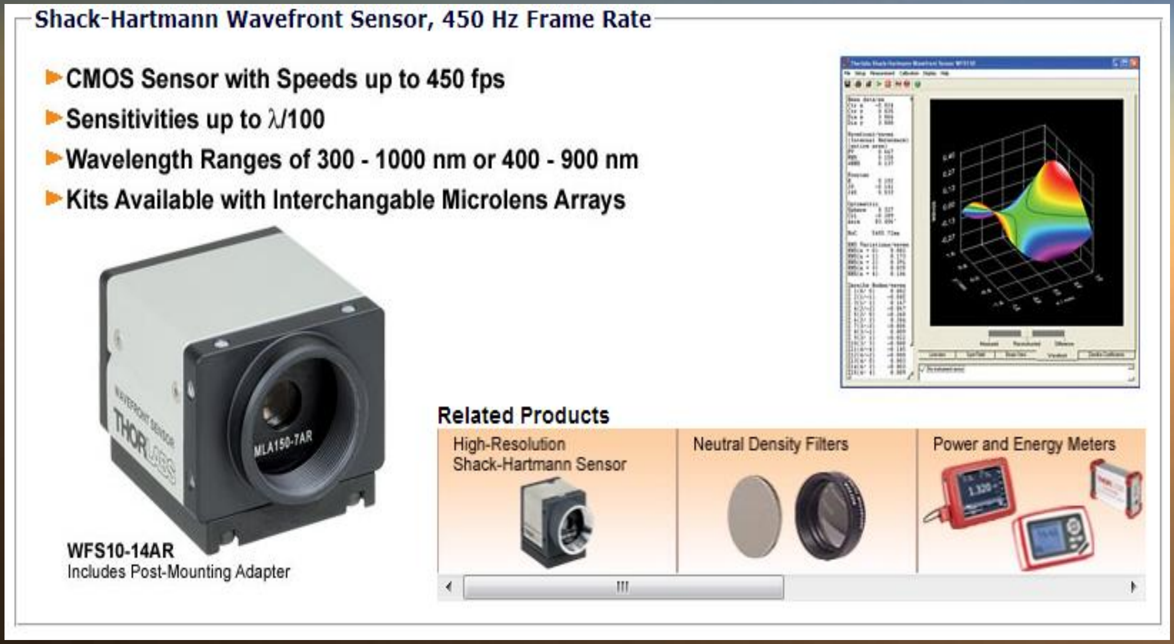
Our FoV can now be as large as 20-30 arcsec !! WOW !!!

Step 1. How measure the distorted wave front ?

We need a Wave Front Sensor (WFS), that is a device able to sense the wavefront by using a “reference star” (as for a conventional autoguider)

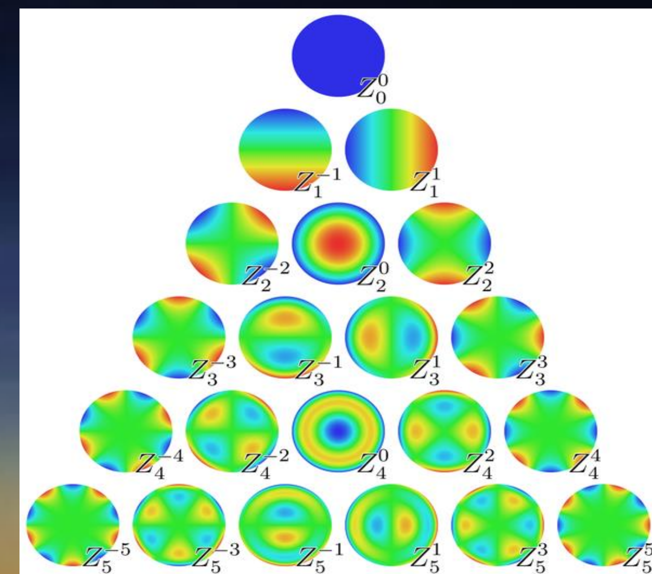
We have different type of WFS...

- Shack-Hartmann WFS … or ...
- Curvature WFS … or ...
- Pyramid WFS
- Others...



Step 2. COMPUTE

the required combination of elementary shapes of the bad wavefront and to send them to a the deformable mirror

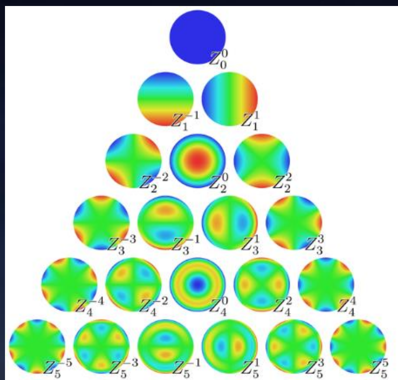


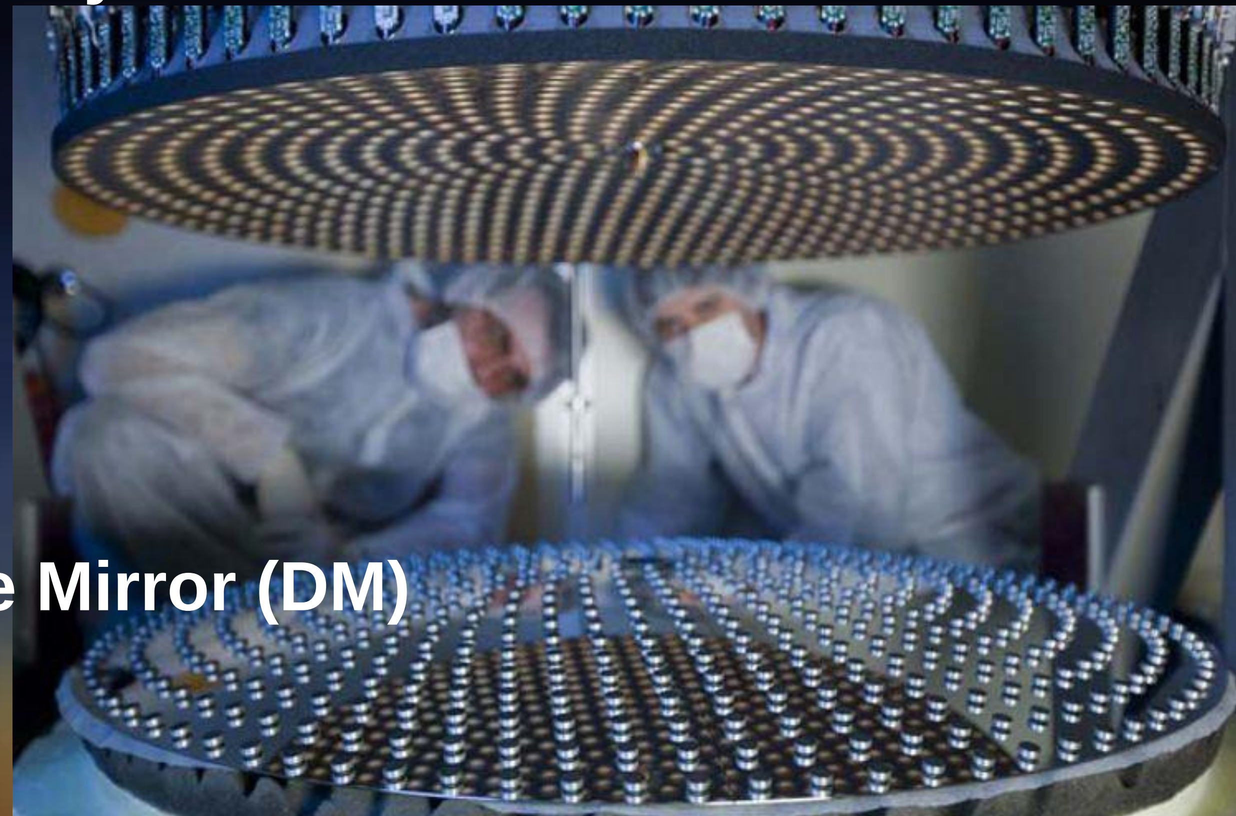
Coutesy of Microgate:
Keck NGWFC
New Generation
Wave Front Computer

We need a Wave Front RECONSTRUCTUR, that is:

*** a FAST COMPUTER + communication system**
*** LOTS of mathematics... too much detais...**

Step 3. APPLY the right combination of the reconstructed elementary modes to the deformable mirror





We need a Deformable Mirror (DM)

- Segmented DMs
- Continuous face-sheet DMs
- Bimorph DMs
- **Adaptive Secondary mirrors**
- MEMS DMs
- (Liquid crystal devices)
- Uff.. too many....

Courtesy of INAF/ADS/MIC
LBT 672 Adatptive secondary

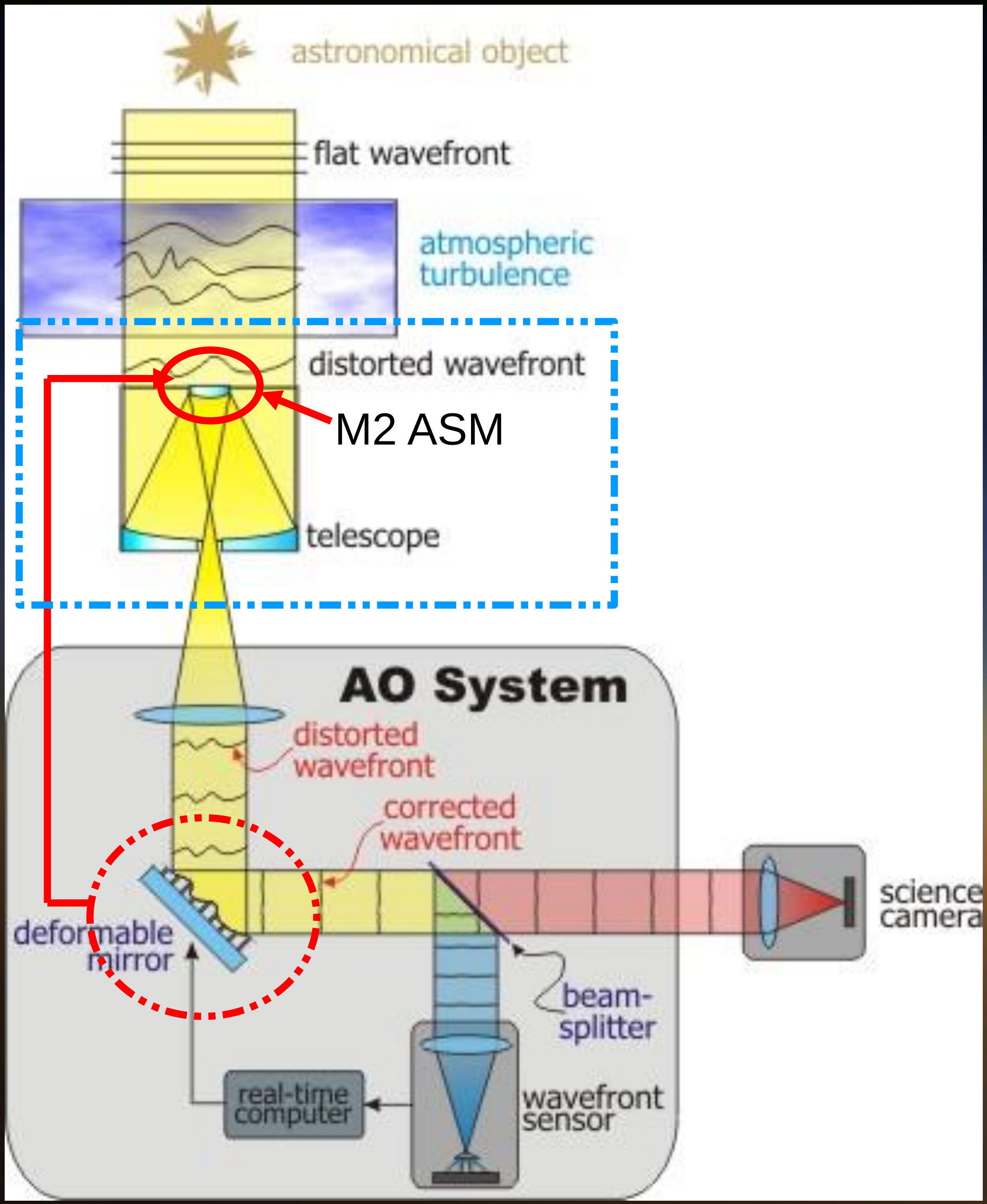
1993: TOWARDS the idea of ADAPTIVE TELESSCOPE

A typical telescope is already a two mirror system, why not using one of thesemirrors to make AO ??? (clear benefit for all the different focal plane instruments)

Prof. Piero Salinari (INAF) had been the first at proposing the challenging idea of transforming the rigid secondary mirror into an very-high-speed deformable mirror. The same could be done on a primary mirror.

The Adaptive Secodary Mirror technology (ASMs) had been develeoped in the last 15 years by INAF and two Italian industries (ADS Int + Microgate + Politecnico Milano) and it is now a breathtaking reality.

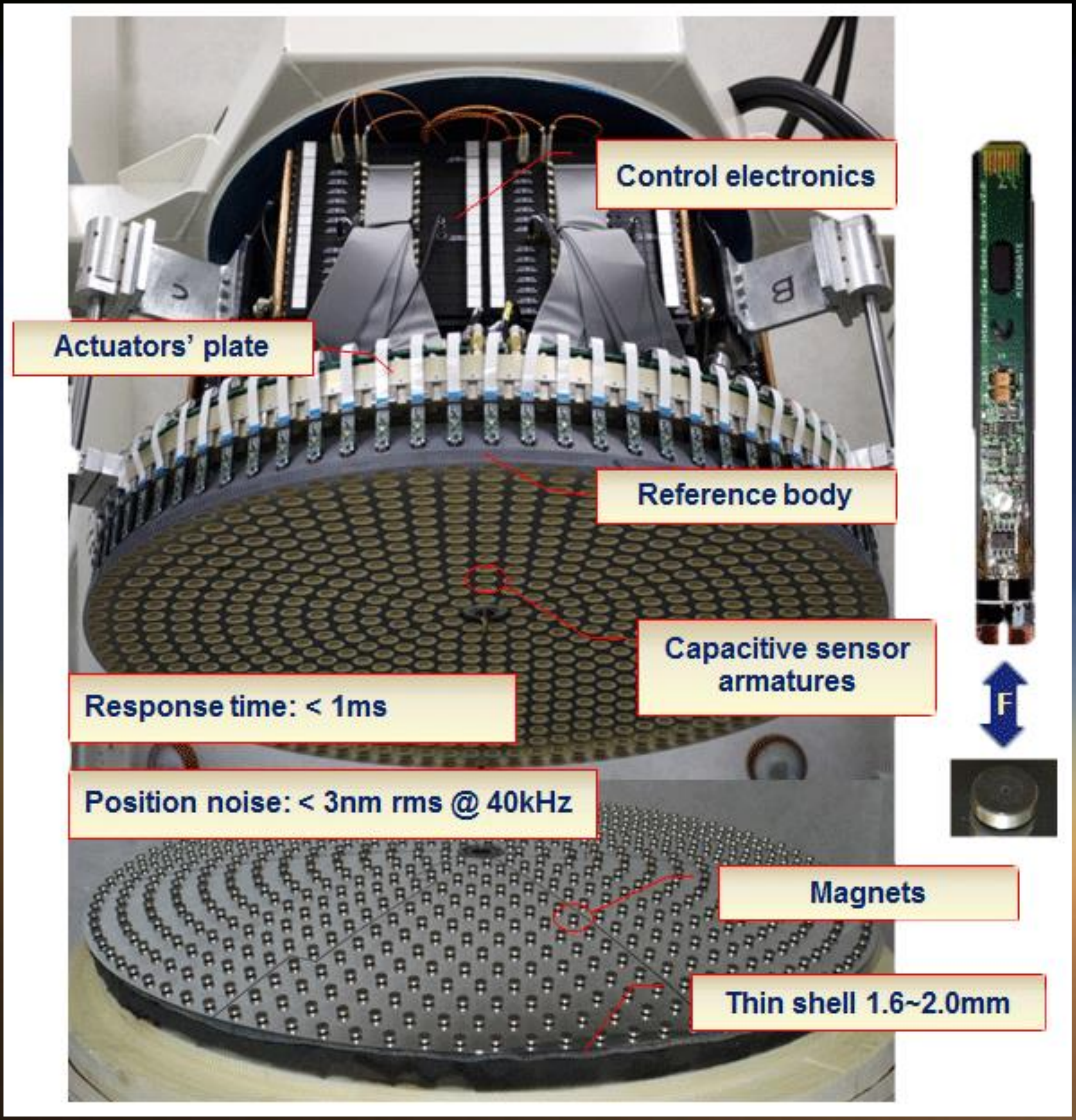
1993: TOWARDS the idea of ADAPTIVE TELESSCOPE



The Deformable Secondary Mirror is PART of the telescope.

Different instrument, at different focal stations can benefit from it !

The Adaptive Secondary Mirrors Technology

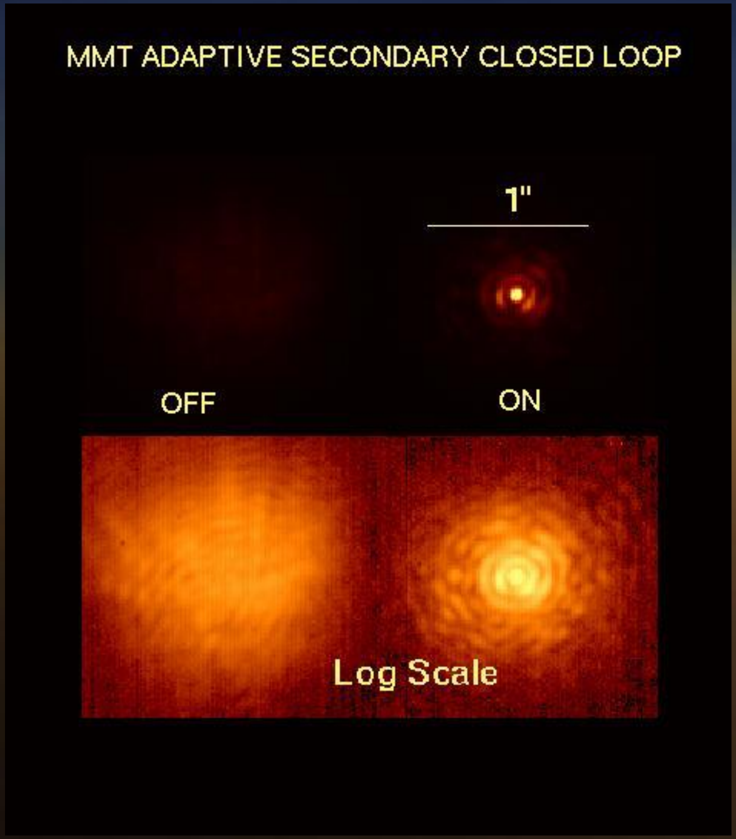


Key components of the Adaptive Secondary Mirror (ASM): LBT case

MMT: The first time ever on a telescope:

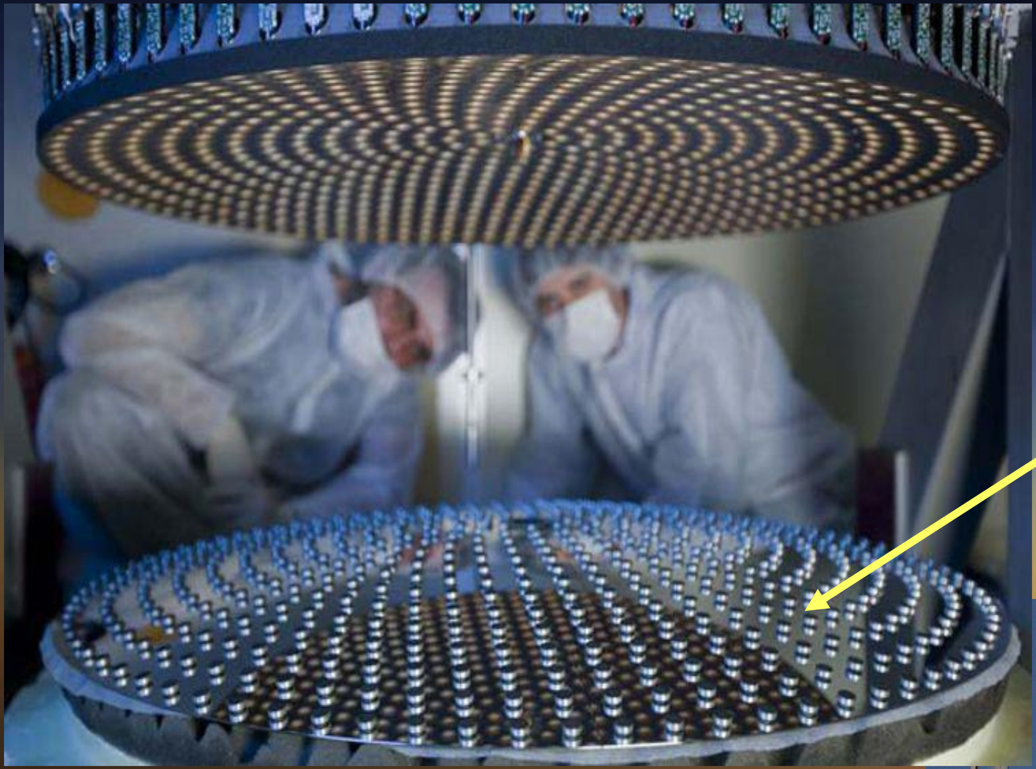
The MMT (UoA, Smithsonian) hosts the first Adaptive Secondary ever built, 336 actuators on 2 mm shell, 600 mm in diameter.

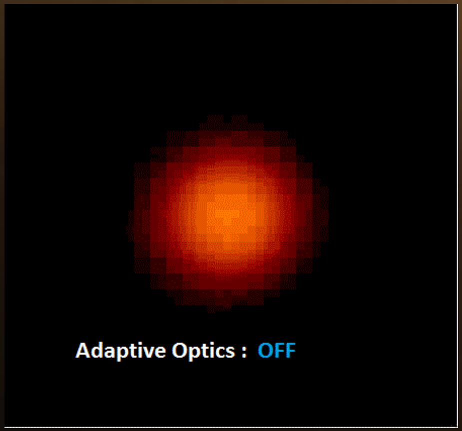
But it was only the beginning

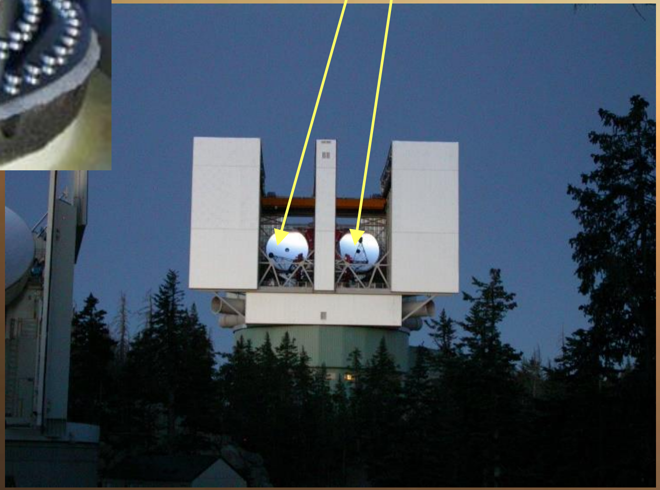


LBT: Two at at time:

An impressive exercise of technology 672 x 2 actuators to deform two 1-meter thin mirrors, only 1.6 mm thickness !!!

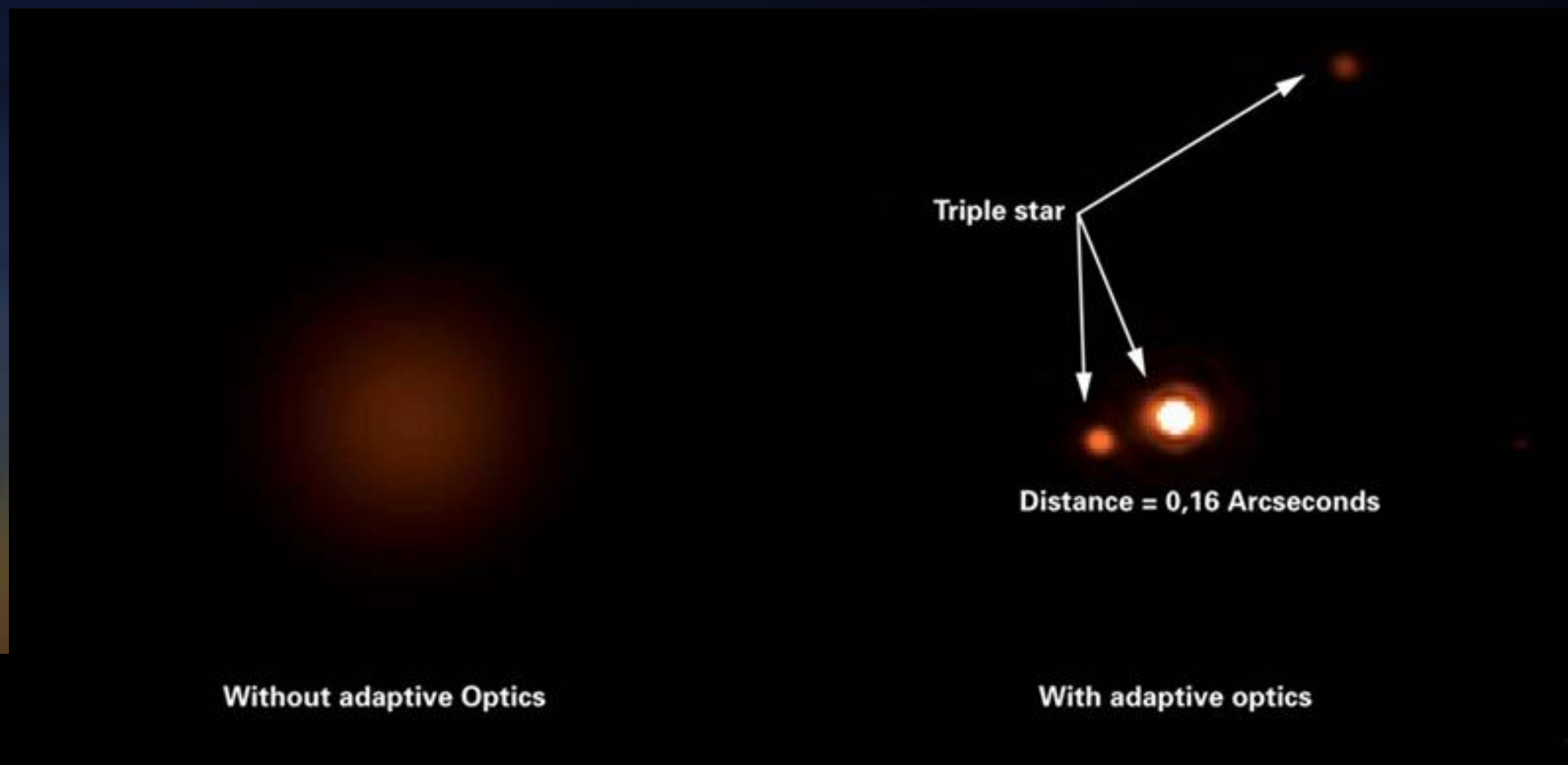


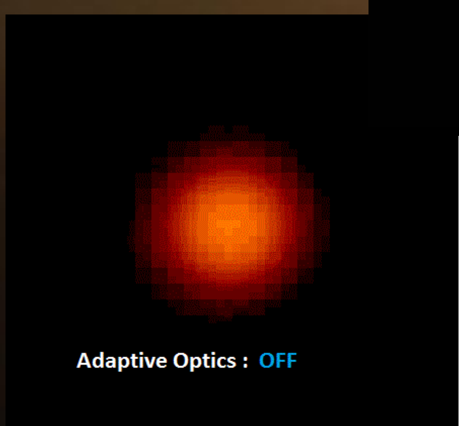




LBT: squeezing the stars (SR up to 0,85)

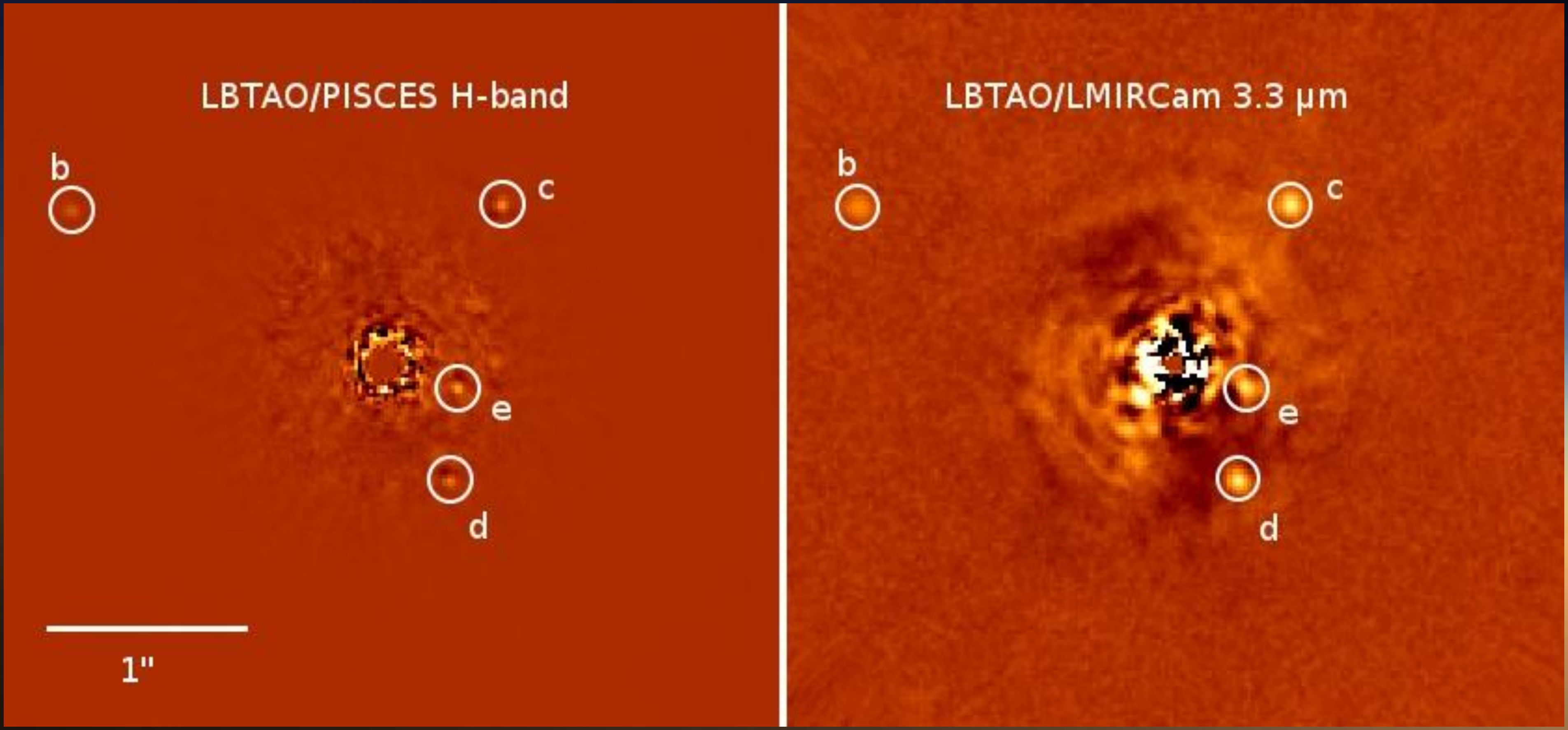
3X sharper then HST in IR-H band.





LBT: squeezing the stars (SR up to 0,85)

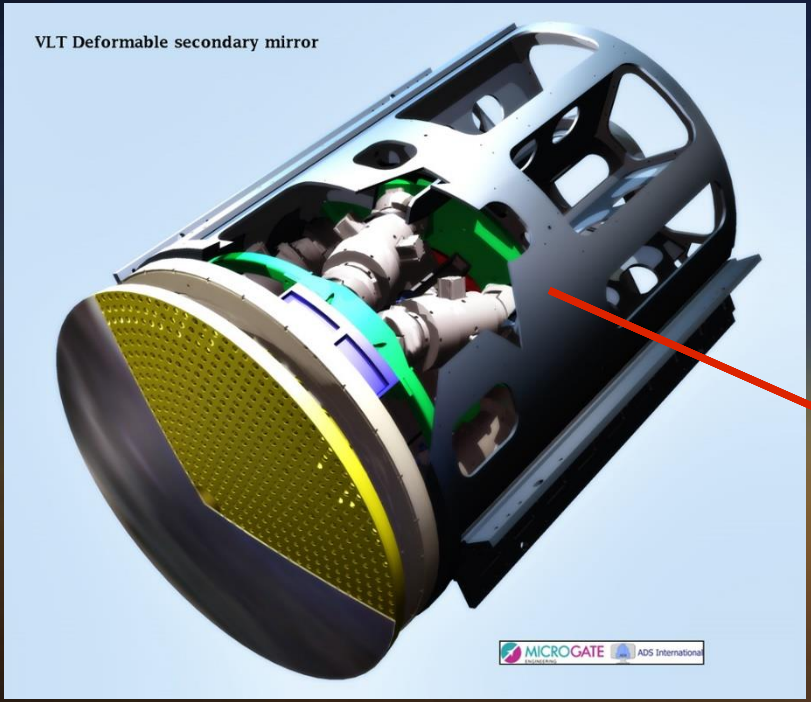
Multiple planetary system: 4 exoplanets in one shot !

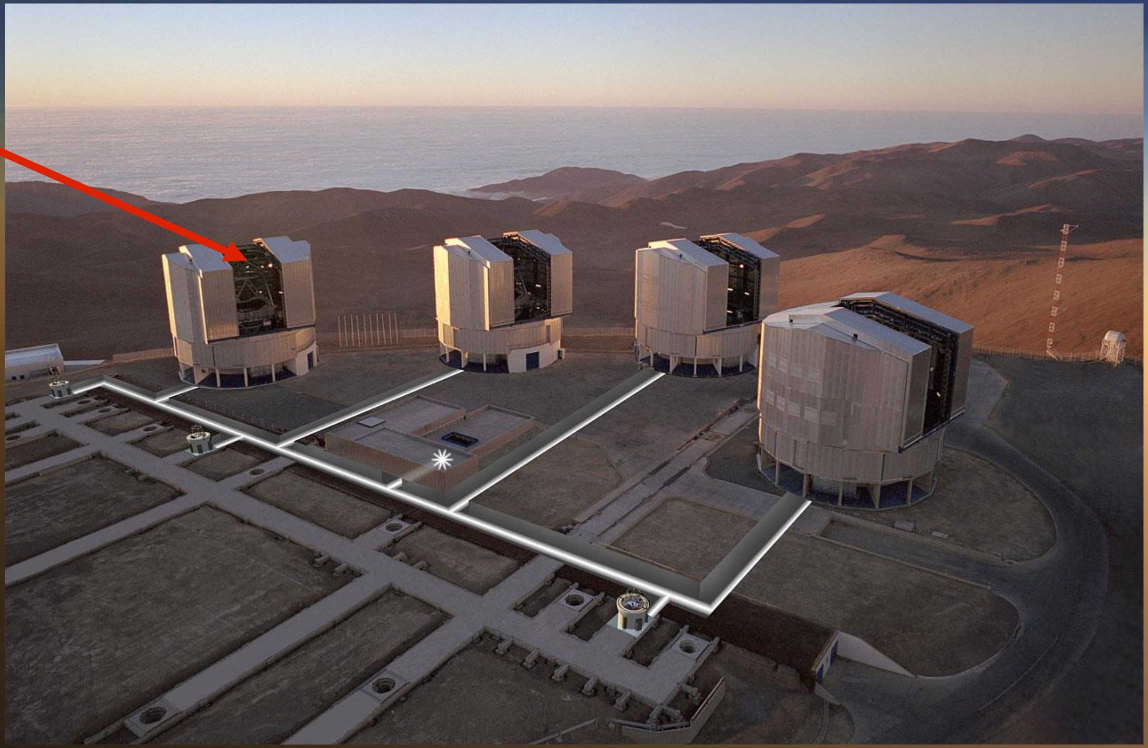


This is the first time the innermost planet, HR8799e, has been imaged at either wavelength.

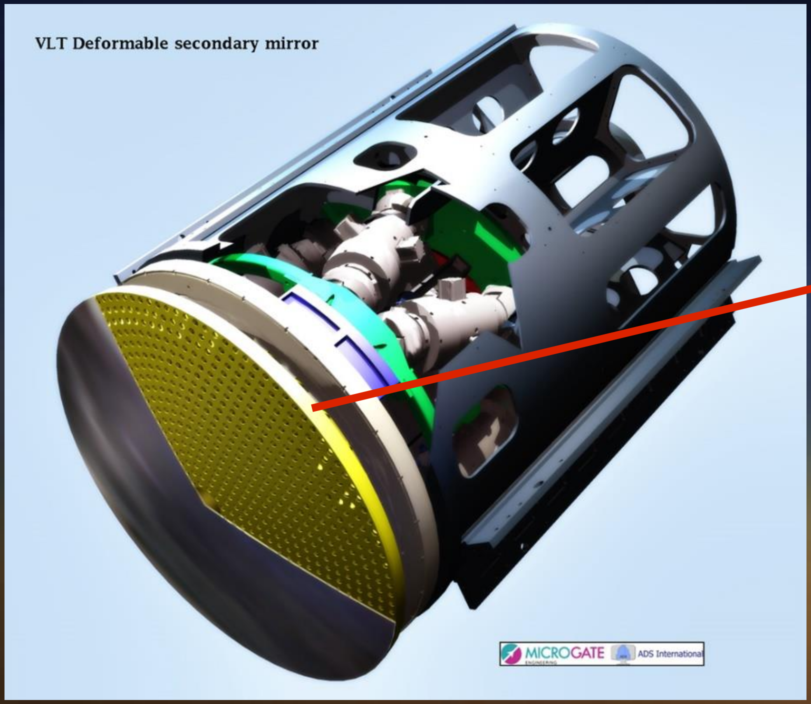
ESO Paranal / VLT-DSM Deformable Secondary Mirror: Increasing the actuuator density:

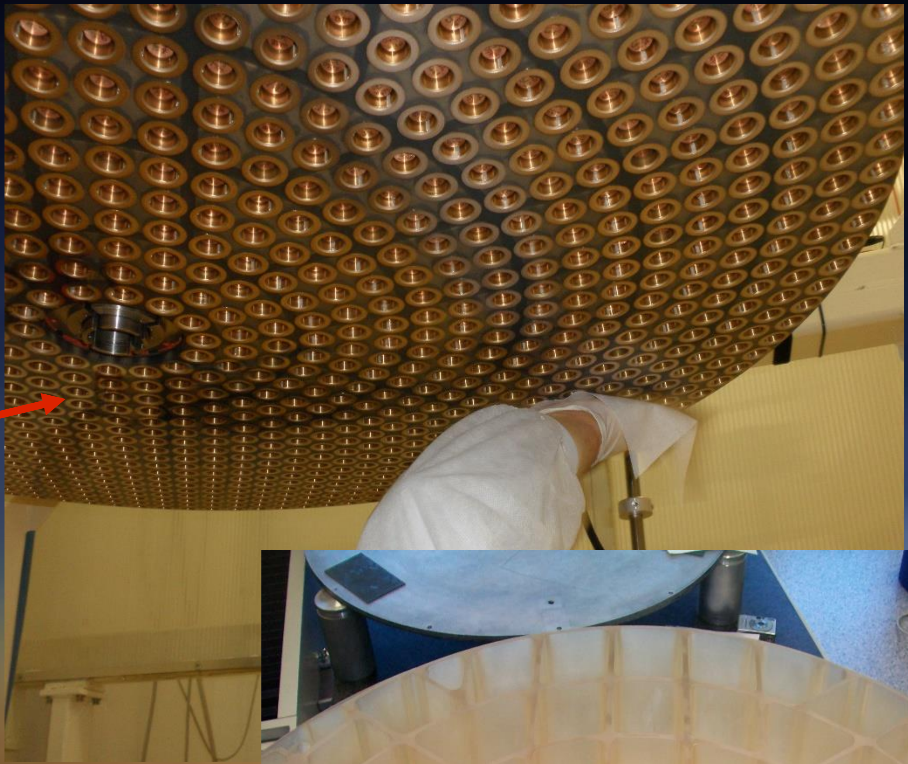
With the DSM the actuator density is pushed even further towards the VIS spectrum: 1170 actuators distributed over a 1120 mm mirror, 2 mm thickness !!! JUST DELIVERED !!!

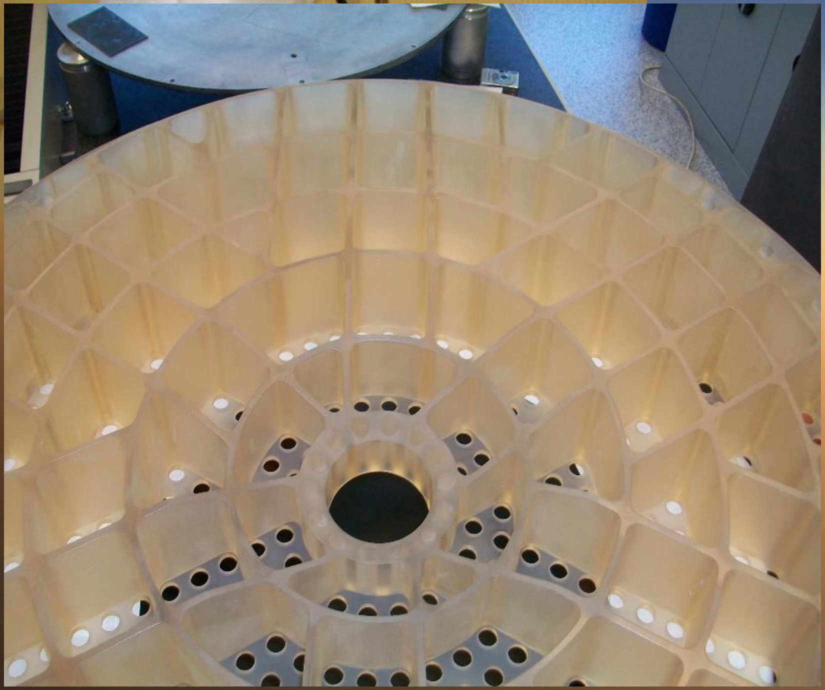




ESO Paranal / VLT-DSM Deformable Secondary Mirror: Increasing the actuuator density:

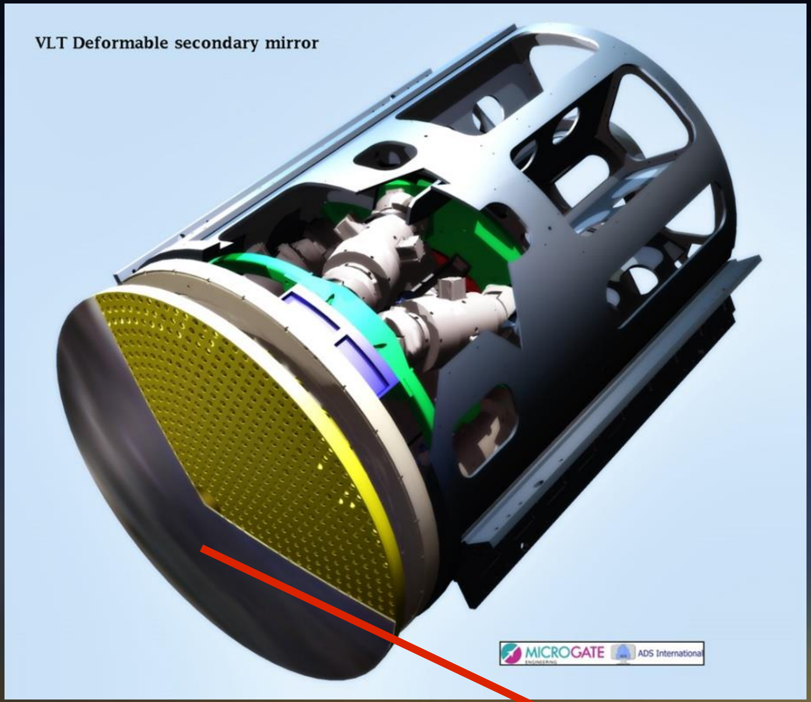


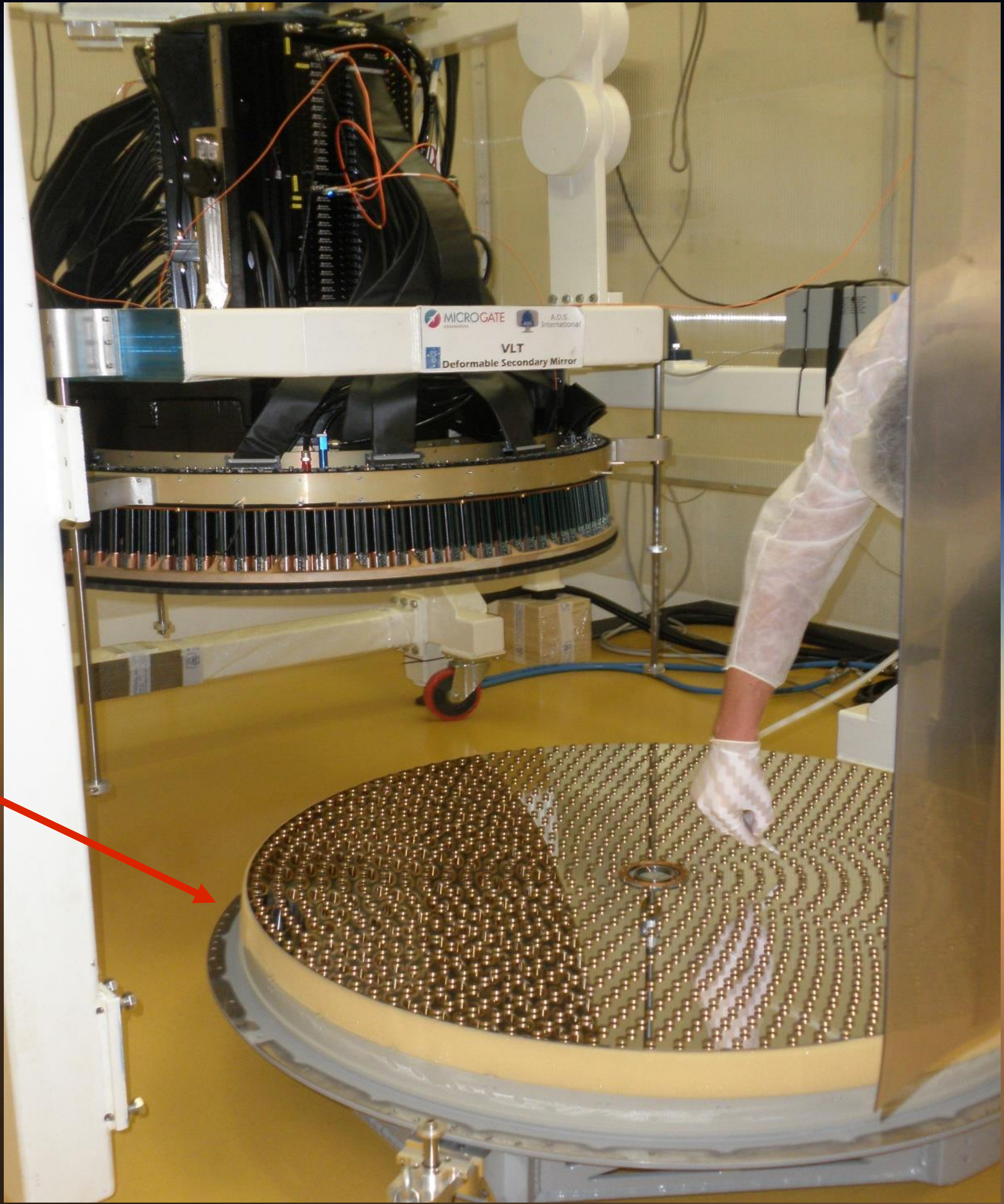




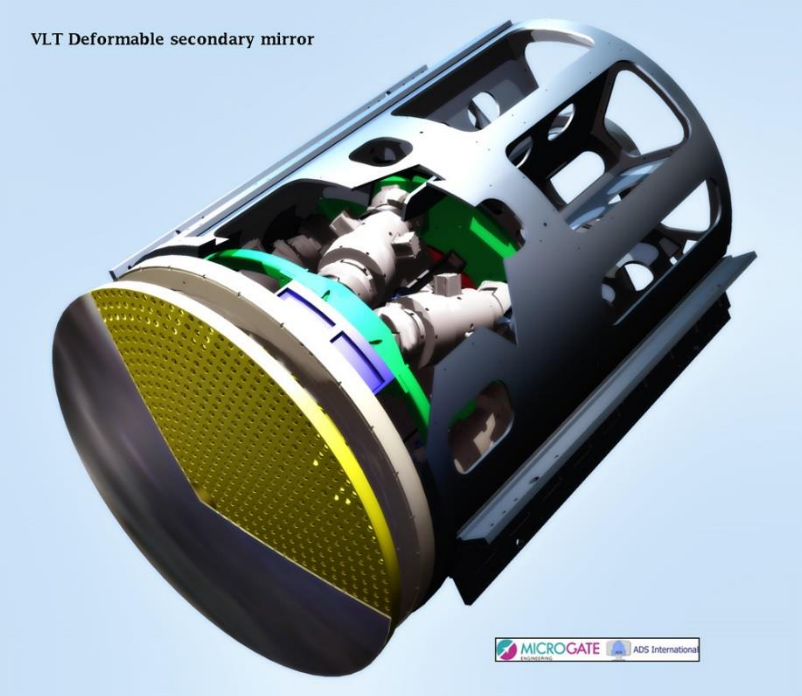
The bed of the deformable mirror and the holes for the magnets

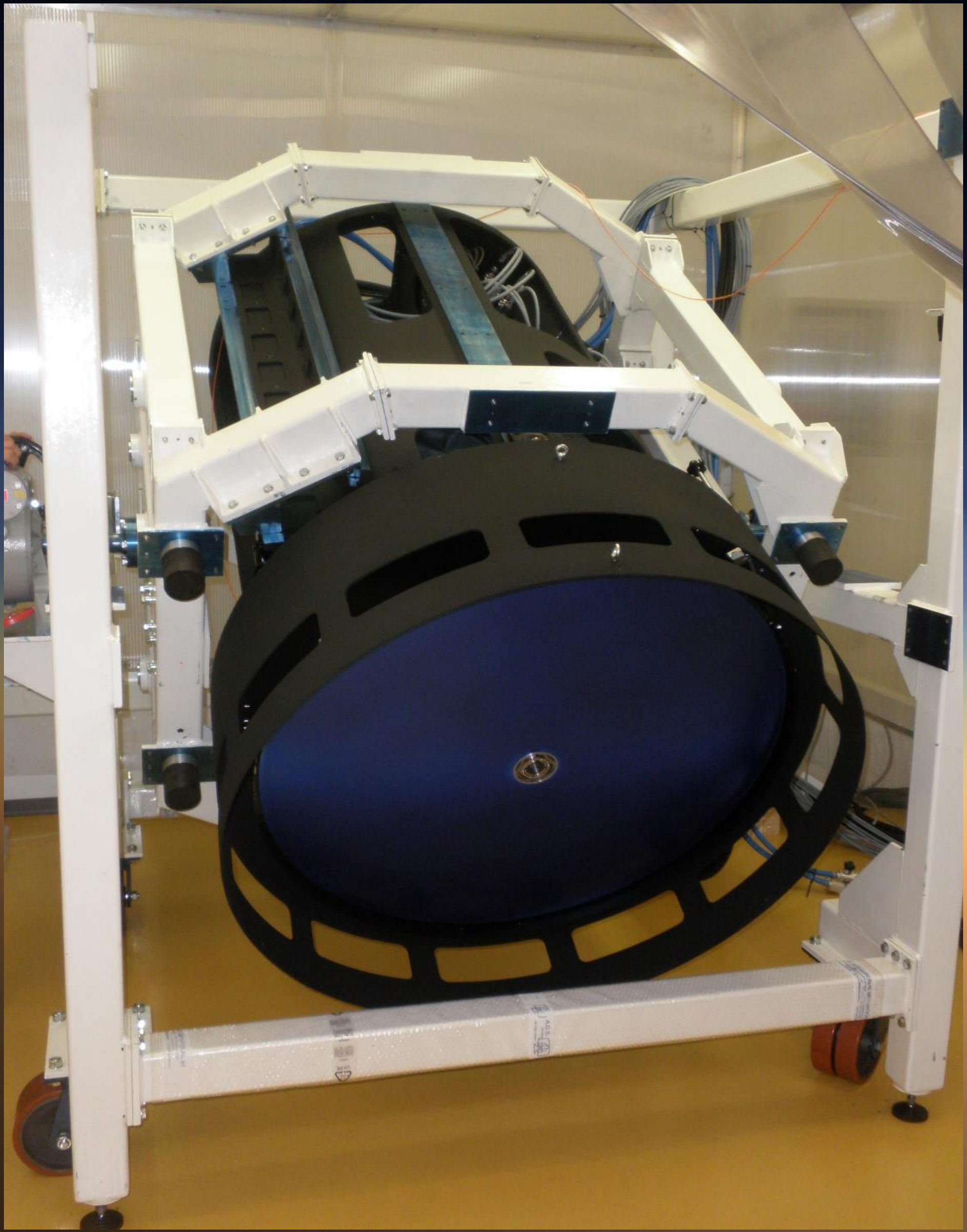
ESO Paranal / VLT-DSM Deformable Secondary Mirror: Increasing the actuuator density:





ESO Paranal / VLT-DSM Deformable Secondary Mirror: Increasing the actuuator density:

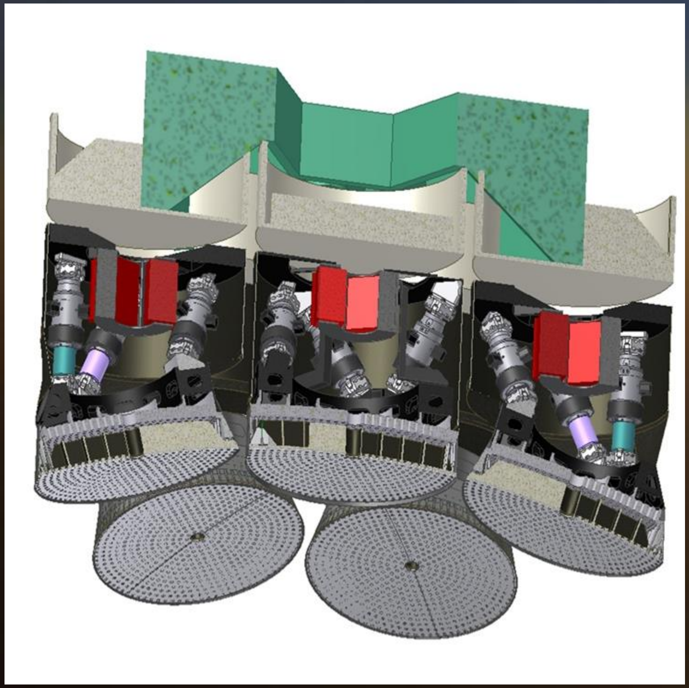


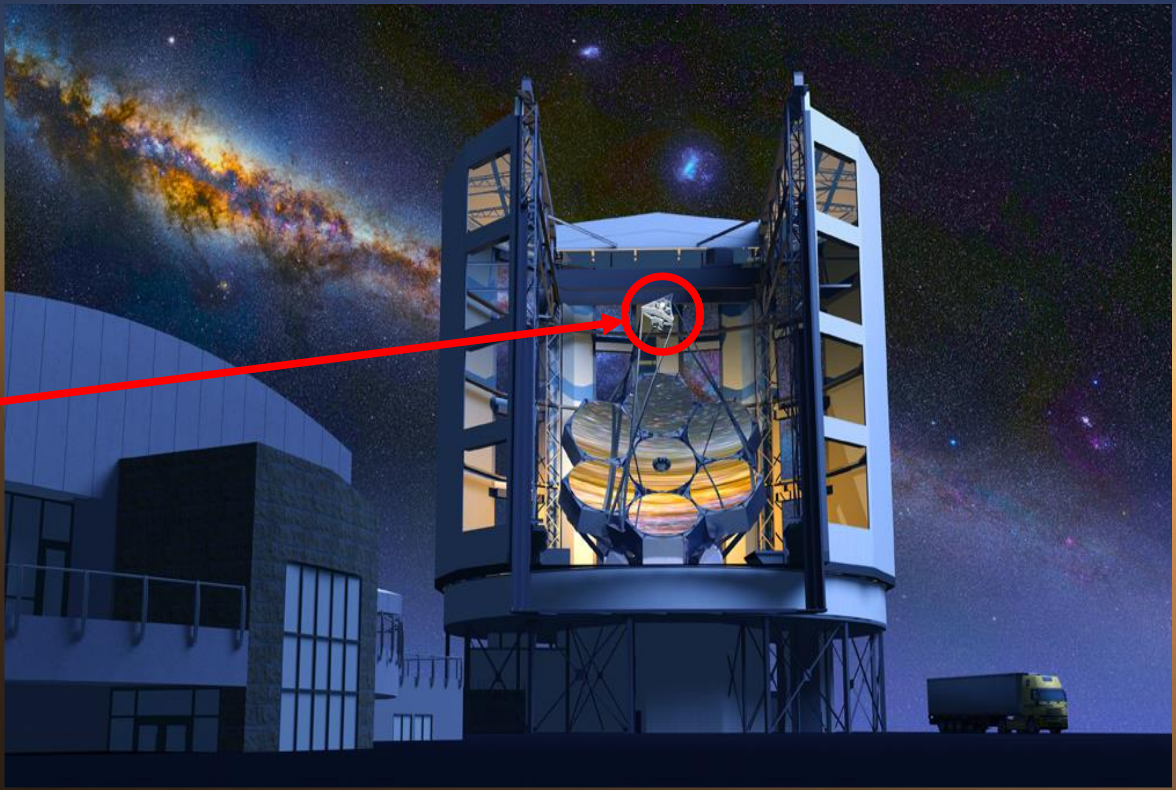


In the land of the ELTs: The Giant Magellan Telescope (2018)

The same ASMs technology born in 1993 is now landing on the Next Generation of Grund Based Telescope: the extremely large telescopes.

The ASM for the GMT is in its design phase: it will feature a daisy-segmented secondary mirror, working in conjunctions with the segment primary: 4704 actuators to the deform the secondary.

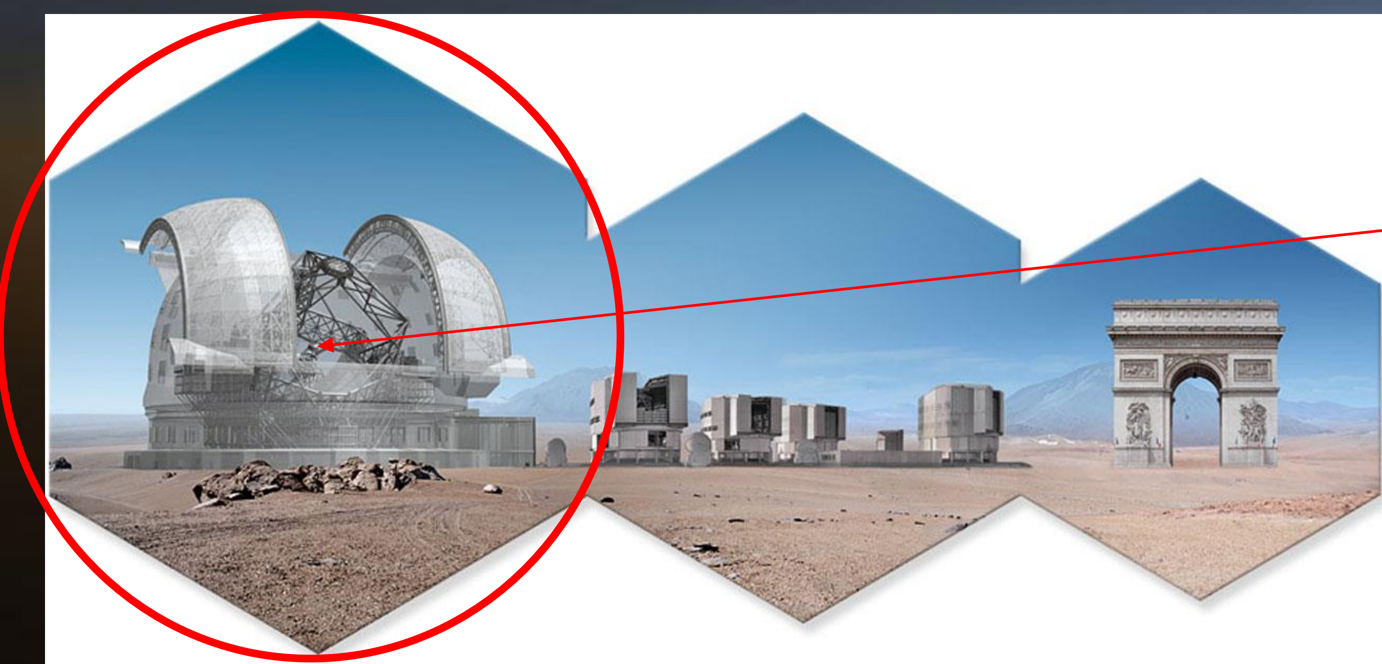


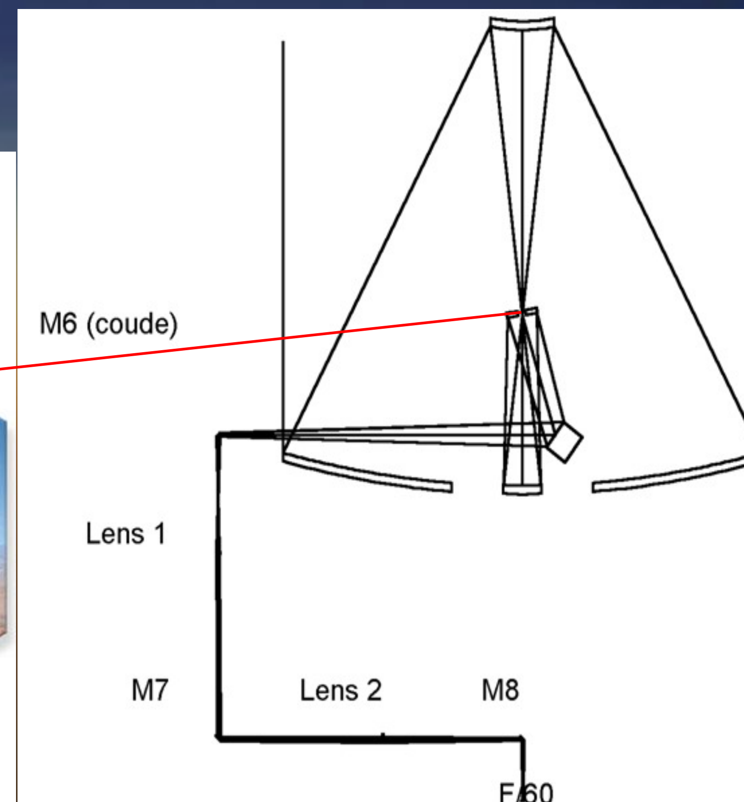


In the land of the ELTs: The ESO European-ELT (2020?)

The flagship of European Astronomy, the E-ELT will feature a novel Optical Scheme with 5 mirrors with a 39 m primary mirror.

Mirror number 4 (M4), about 2.4 m diameter, will be the adaptive part of the Telescope. It will feature about 5200 Actuators.





AO for amateur

Key Points

Where all-turbulence “is uniform”

Where tip/tilt only (wandering) “is uniform”

* Isoplanatic and isokinetic angles are a BIG LIMITATION
* Costs
* Expected performances over a given FoV

AO for amateurs

Traditional “AO” system for TIP/TILT correction

- VERY effective as fast guiders for rigid body movements of the field (Mounts tracking errors, wind gusts on telescope tube ==> “rigid depointing”)
- “Partial correction” of tip-tilt component of turbolence

Why “Partial” :

Isokinetic angle ~ 1 to 2 arcmin at best sites (Hawaii)
<< 1 arcminutes at regular EU sites

==> tip/tilt systems cannot fully correct atmospheric tip/tilt turbolence over WIDE fields simply because such correction would be different in the different part of the frame (i.e. 20” f/8 + full format = 30 arcmin >> Isokinetic angle). As we get far from the guide star the quality decreases.

“EXTREME”AO for “amateurs” (?)

* FoV MUST be sacrified to a few arcsecs (< 10.. 20 arcsec? Depends on expectations...)

An higher number of “mirror modes shapes” must be compensated, not only tip/tilt... but also higher orders (say up to 20/30 modes of deformation).

The Hardware is available and <u>even if expensive could be considereed for small clubs or small institutions</u>.

TARGET : ~ 0,1 arcsec resolution for 0,8-1,5 meter class telescopes and from regular sites (1-1,5” seeing class).

A Laser Guide Star will be needed to operate on full sky with a suitable brighgt reference star.

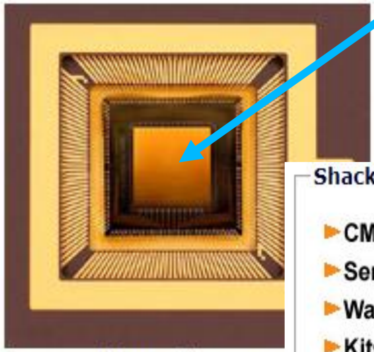
“EXTREME”AO for “ amateurs” (?)

Examples of HW available...

Small MEMS deformable mirror with 32, 140 or more actuators.

* 1.5 µm DM and SLM capable of 20 kHz.

Quick Quote



Mirror Close-up

Product PDF

Looking for a com
adaptive optics sou
Click here to find ou

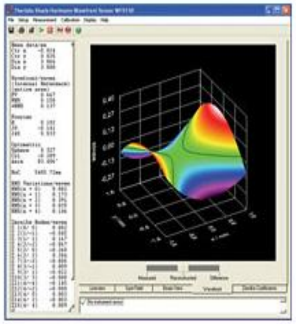
DM Selection Chart

	Multi- 1.5	Multi- 3.5	Multi- 5.5	Multi- SLM
Stroke	1.5 µm	3.5 µm	5.5 µm	1.5 µm
Aperture	3.3 mm	4.4 mm	4.95 mm	3.3 mm
Pitch	300 µm	400 µm	450 µm	300 µm
Mechanical Response (10%-90%)	<60 µs	<100 µs	<500 µs	<40 µs
Approx. Interactuator Coupling	15%	13%	22%	0%

Shack-Hartmann Wavefront Sensor, 450 Hz Frame Rate

- CMOS Sensor with Speeds up to 450 fps
- Sensitivities up to λ/100
- Wavelength Ranges of 300 - 1000 nm or 400 - 900 nm
- Kits Available with Interchangable Microlens Arrays

WFS10-14AR
Includes Post-Mounting Adapter



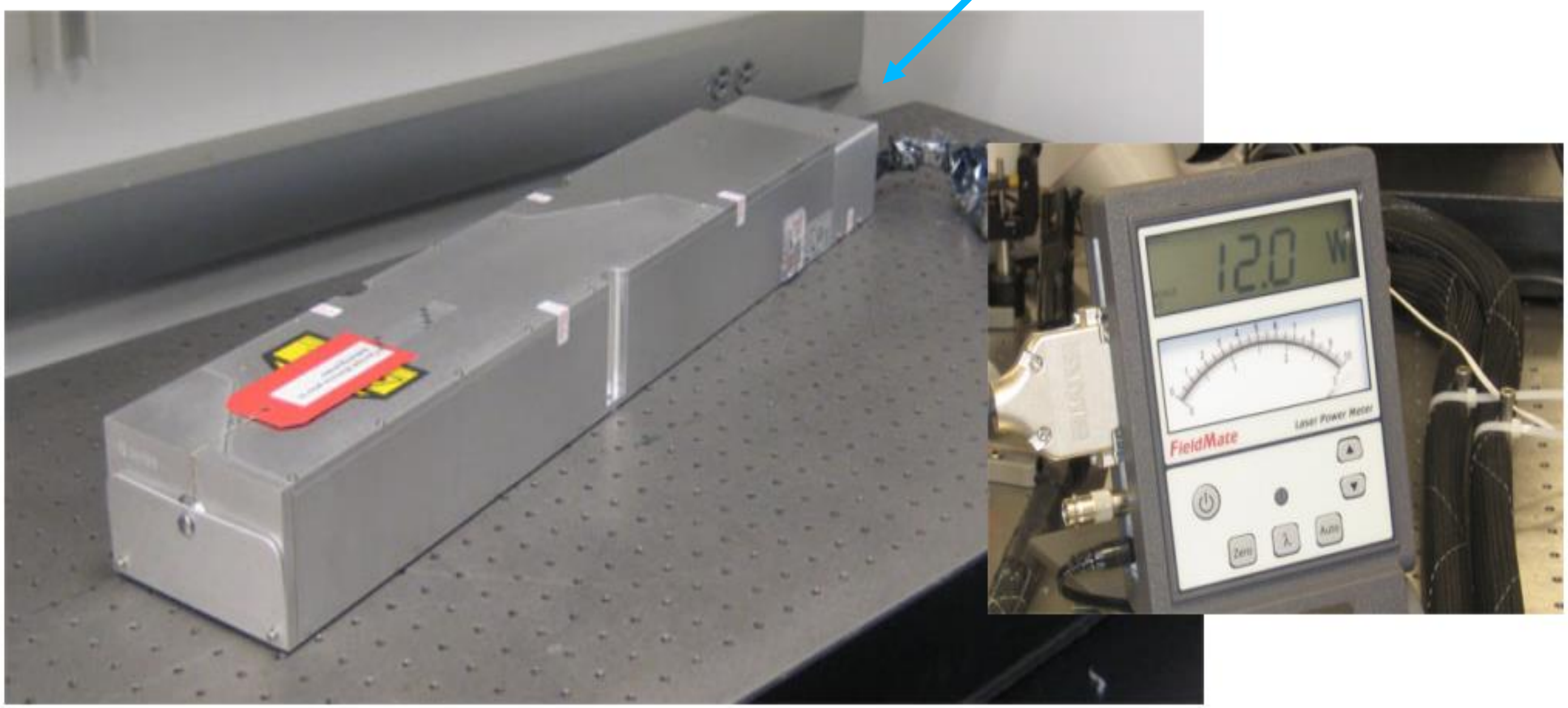
Related Products

WFS+DM = ~~ 25 K€ UP, depends on complexity

“EXTREME”AO for “amateurs” (?)

Examples of HW available...

Suitable, very commercial
Laser system/s



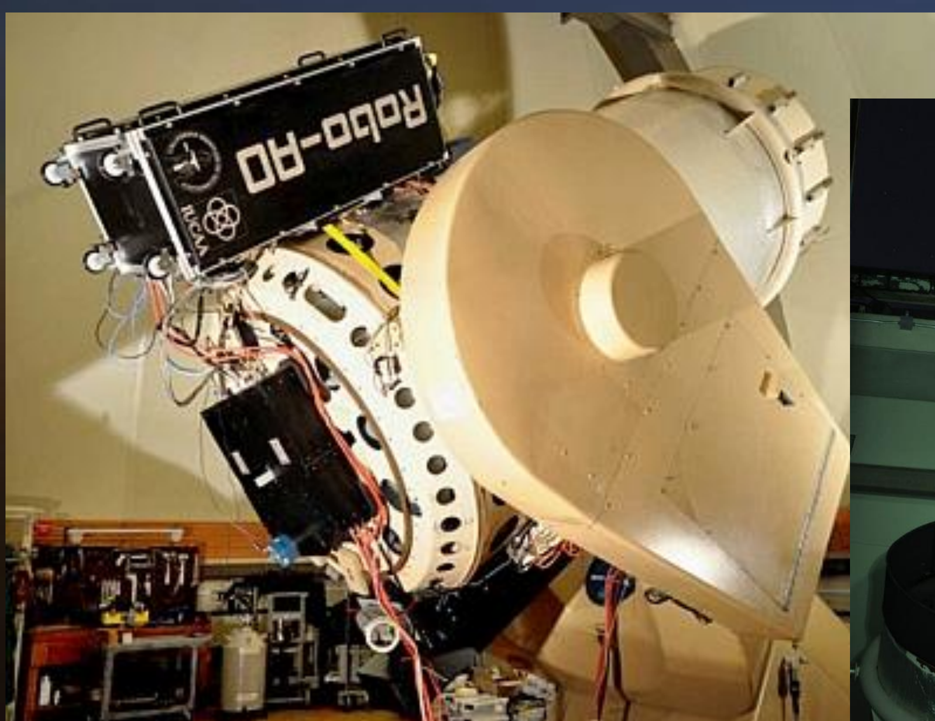
Commercial 12 W @ 10 kHz, λ=355nm

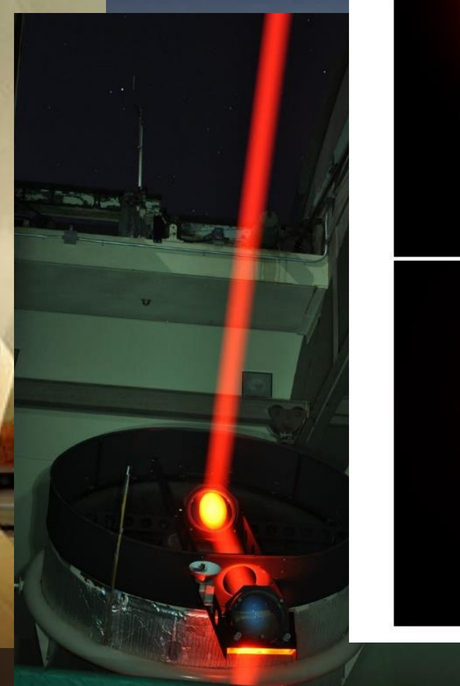
“EXTREME”AO for “amateurs” (?)

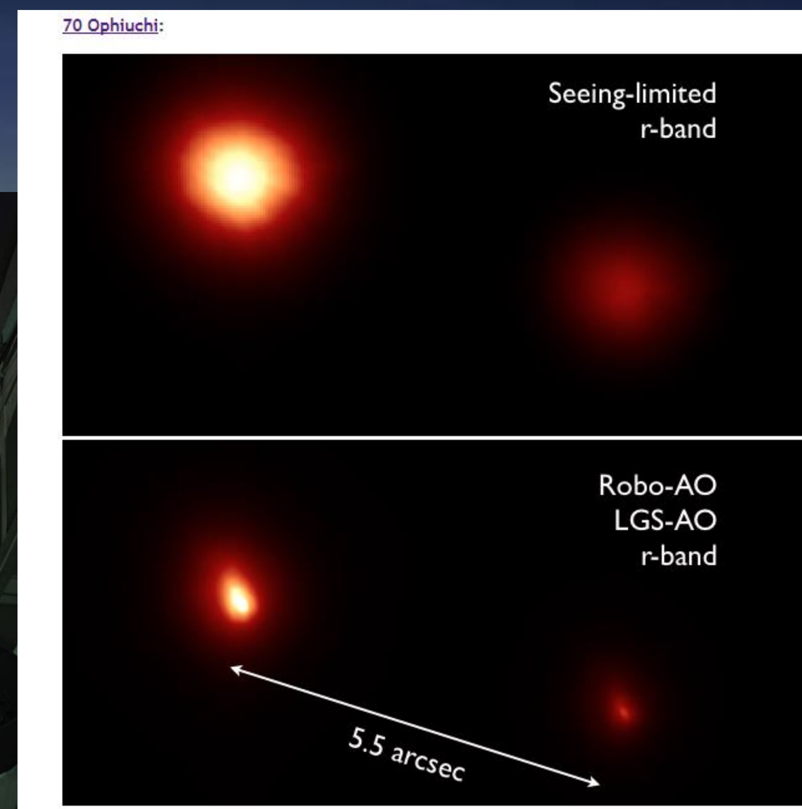
EXAMPLES: ? Here you go... ROBO-AO

http://www.astro.caltech.edu/Robo-AO/

Autonomous laser-adaptive-optics for few-meter-class telescopes, ready to be replicated on other institutions/high end groups

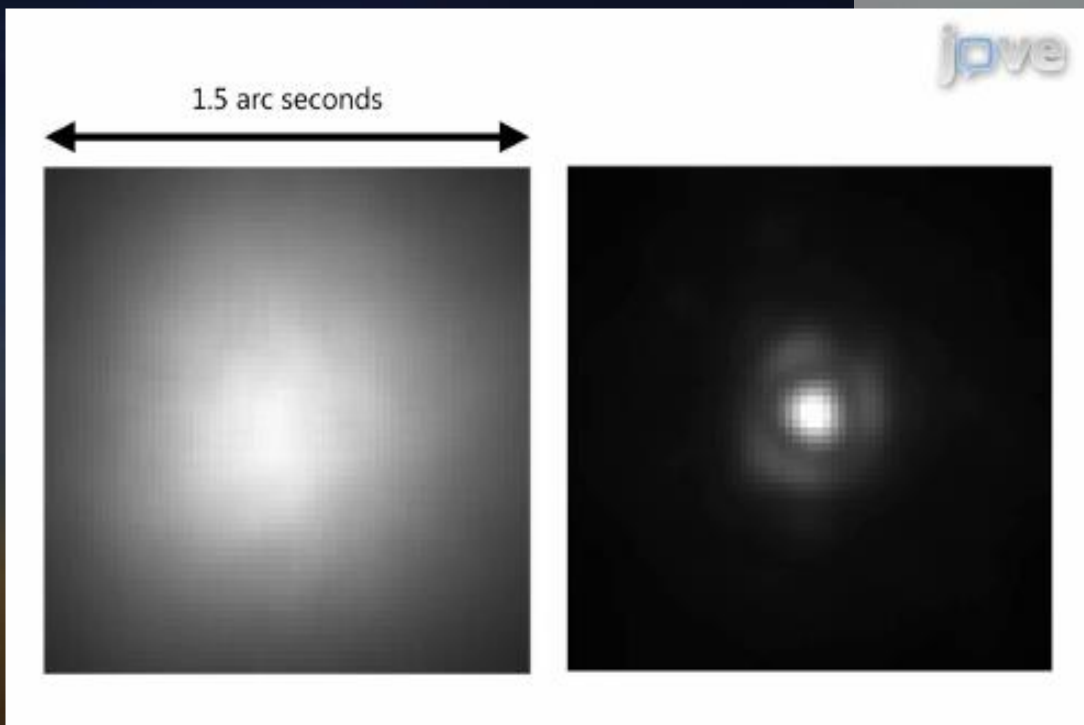






“EXTREME”AO for “amateurs” (?)

ROBO-AO



OFF

ON

http://www.jove.com/video/50021/bringing-the-visible-universe-into-focus-with-robo-
ao

Credits:

ESO
University of Arizona (UoA)
Smithsonian Institution
MMTO
LBT Corporation
GMT Corporation
INAF
Microgate
ADS International
California Institute of Technology
Dr. P. Salinari (INAF Arcetri)
Dr. A. Riccardi (INAF Arcetri)
Dr. R. Ragazzoni (INAF Padova)
Claire Max. (UC Santa Cruz)
www.subarutelescope.org
www.telescope-optics.net
…..

I really want to thank all of the above institutions, companies and individuals
For questions, errors and other:

plazzarini@tiscali.it

Ciao !