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Winter College on Optics in Environmental Science

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Adaptive Optics: Systems and Applications

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Adaptive Optics: Systems & Applications

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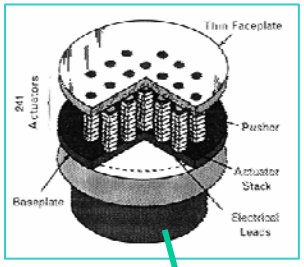
William Herschel Telescope with GLAS Rayleigh Laser Guide Star

Photo: Tibor Agocs, Isaac Newton Group of Telescopes

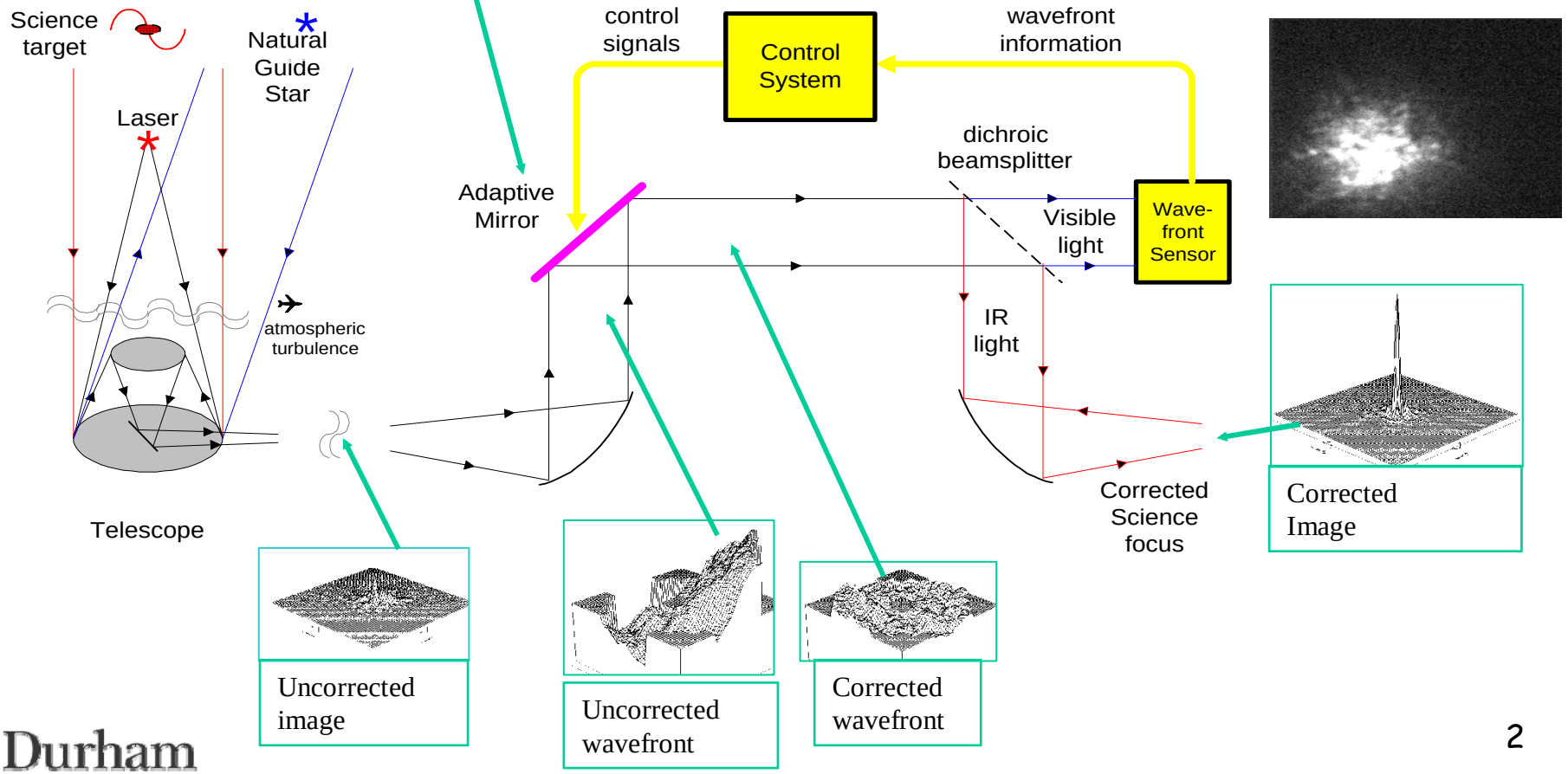
Wavefront Correctors

Generic Astronomical Adaptive Optics

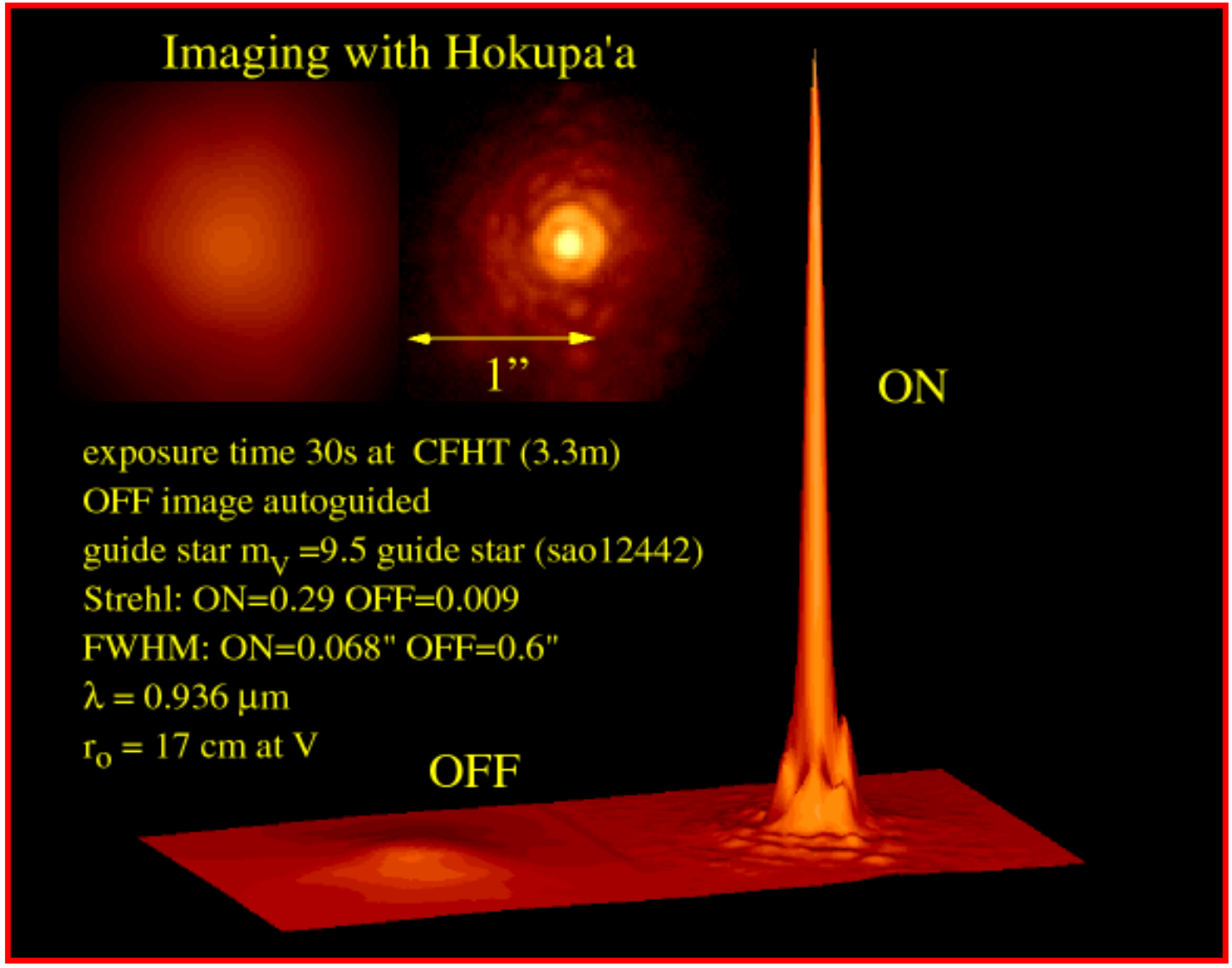


Basic Single Conjugate AO system

Correcting the fluctuating aberrations caused by atmospheric turbulence above ground-based optical and near-infrared telescopes



University of Hawaii AO System



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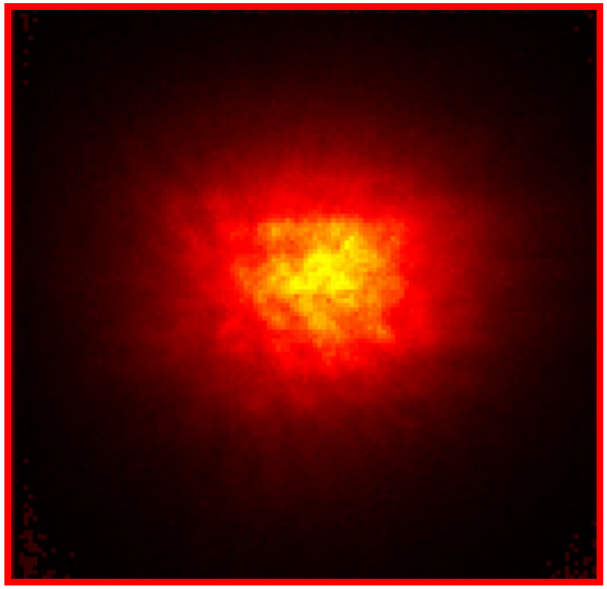
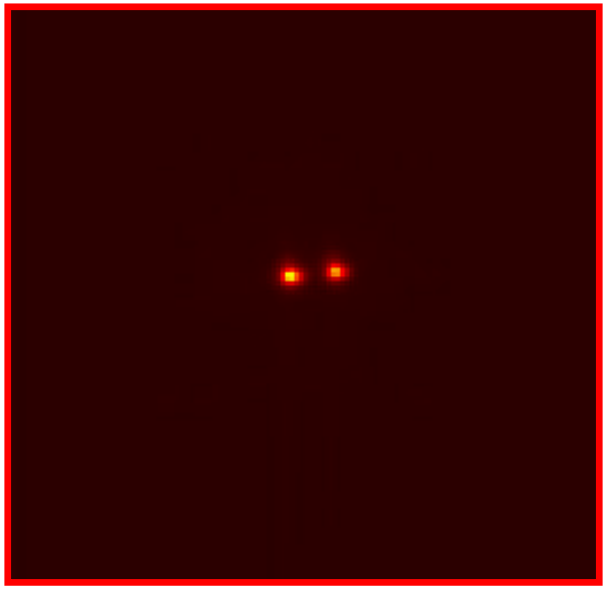
USAF - Starfire Optical Range





Albuquerque, NM, USA

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Asteroid - Vesta

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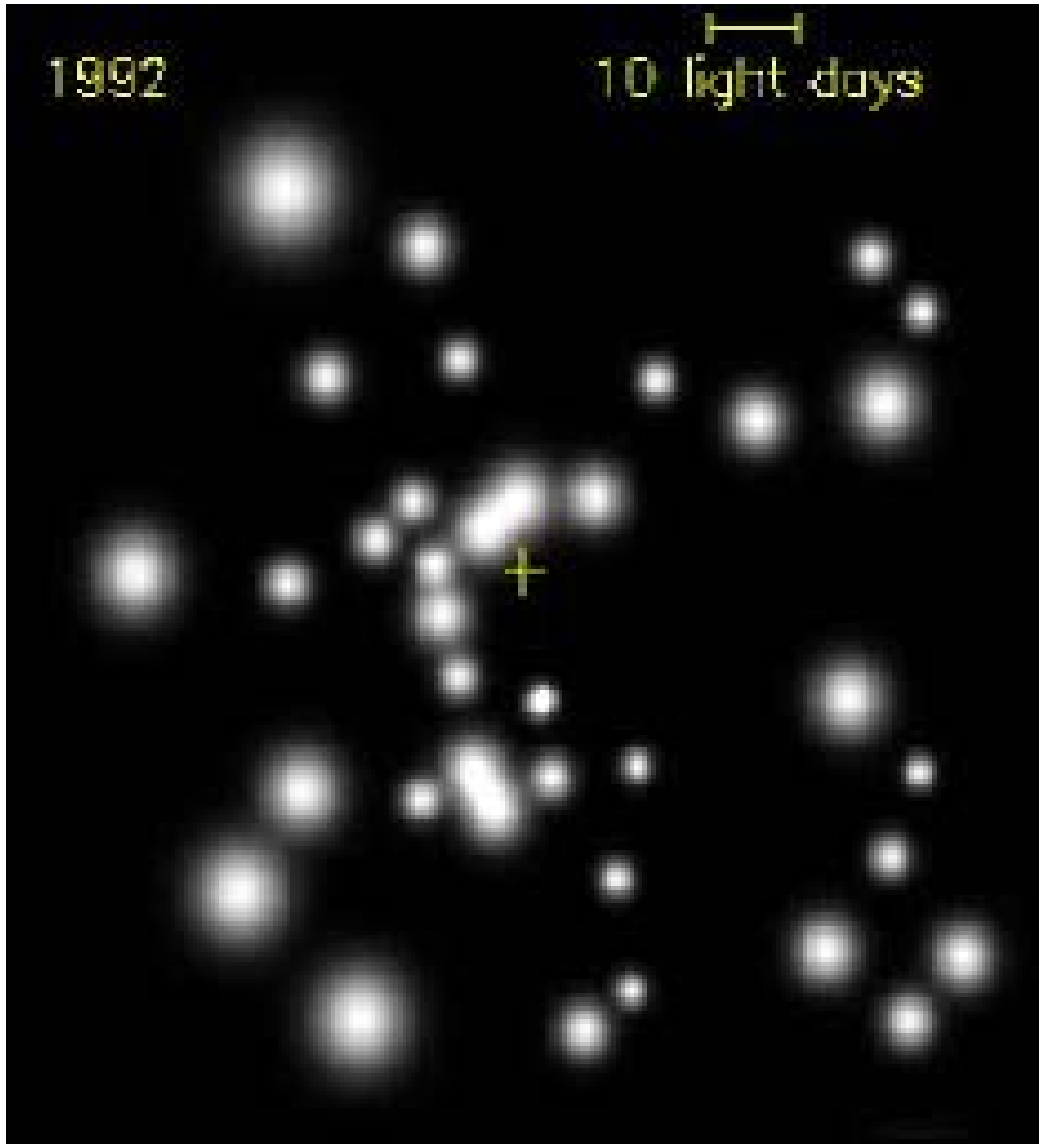

Star orbiting
a black hole at
the centre of
the Milky Way
(courtesy of ESO)

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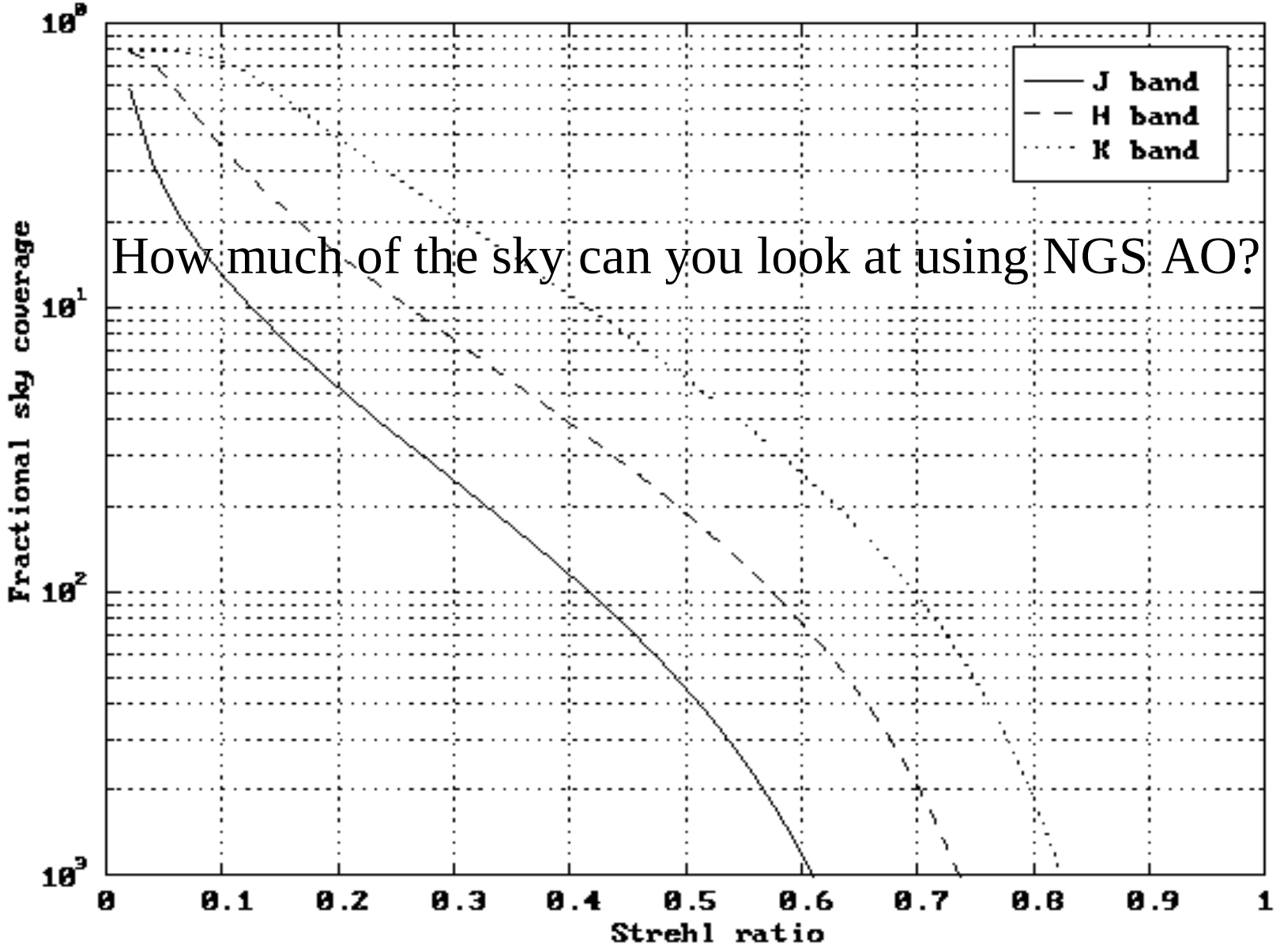
Astronomical AO
- State of the Art

- All major astronomical observatories have adaptive optics systems.
- The technology is maturing
- The number of science papers exploiting AO is increasing

… so what's the problem?

- We can only look at a tiny fraction of the sky
  - Requires Laser Guide Stars
- Field of view is very narrow. Requires…
  - MCAO (multiconjugate AO)
  - GLAO (ground layer AO)
  - MOAO (multi-object AO)
- Systems all work in the infrared
  - Visible AO requires XAO (Extreme Adaptive Optics)



(Courtesy: *Brent Ellerbroek and David Tyler, Phillips Laboratory)*

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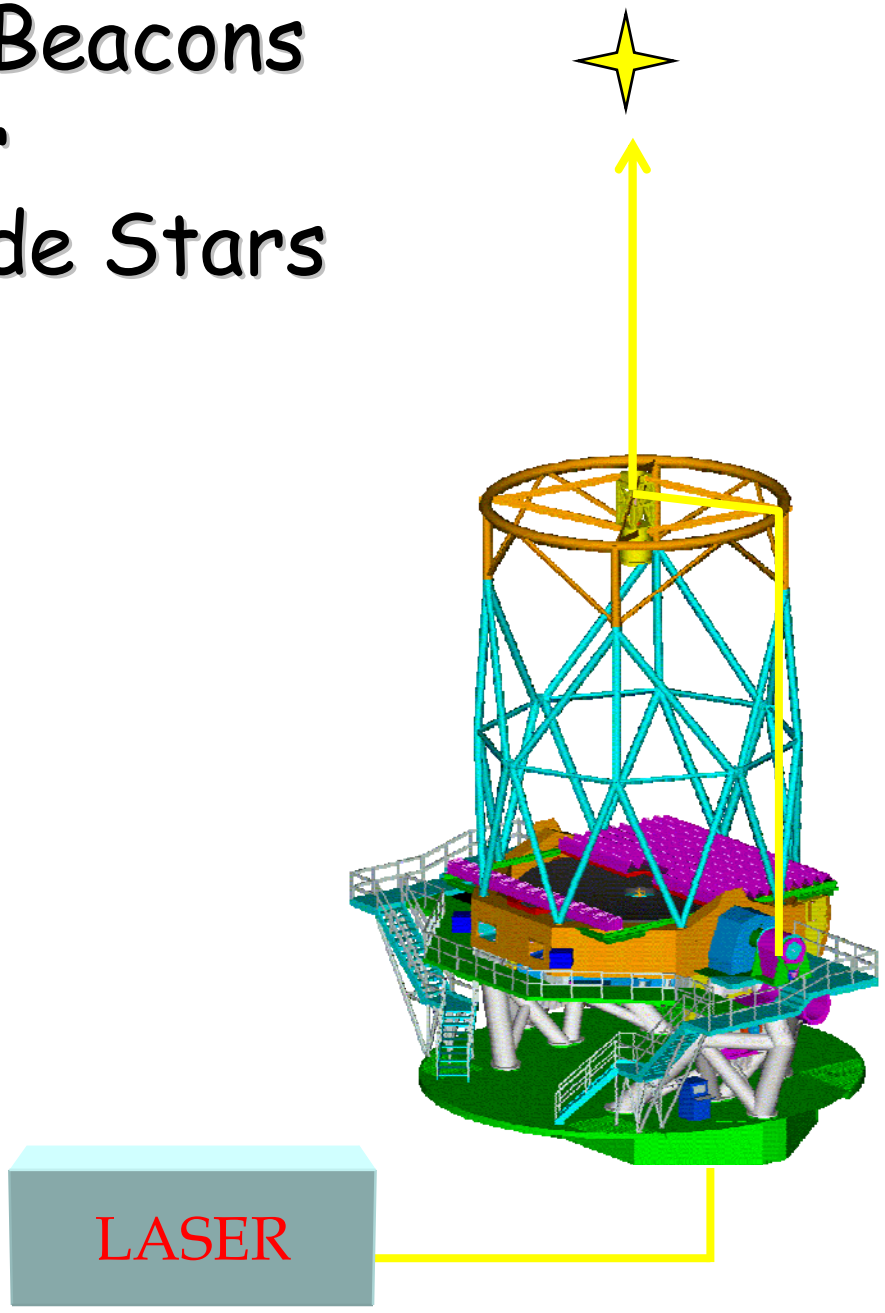
A: Laser Beacons or Laser Guide Stars

The solution to the lack of suitable guide stars is to create an artificial one by shining a high-power laser into the atmosphere



(Courtesy of Gemini)

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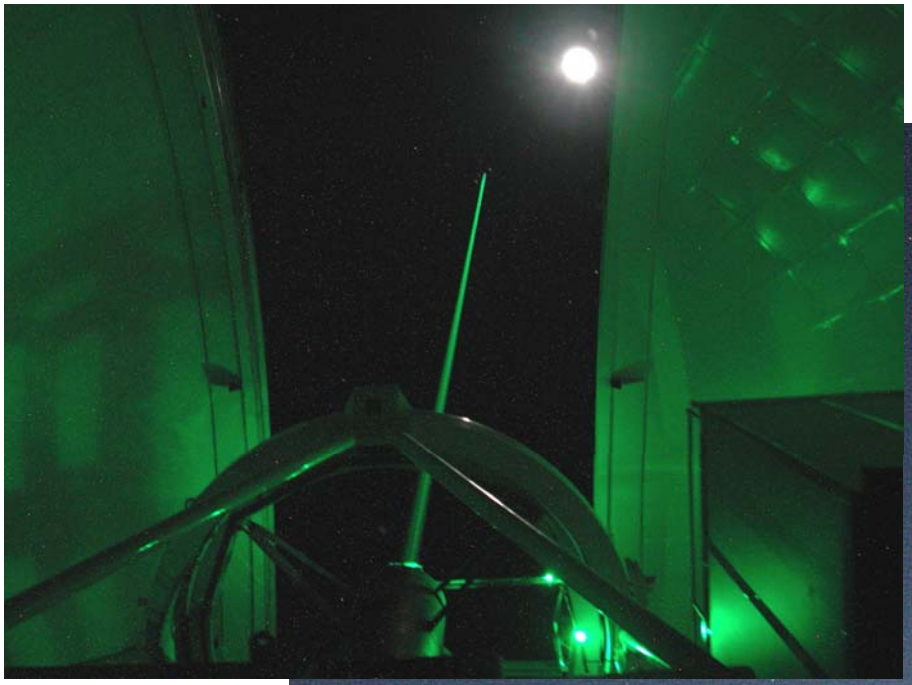
Sodium Layer (~90km).
This picture shows the aurora and sodium layer photographed from space

Durham's Rayleigh Laser Guide Star



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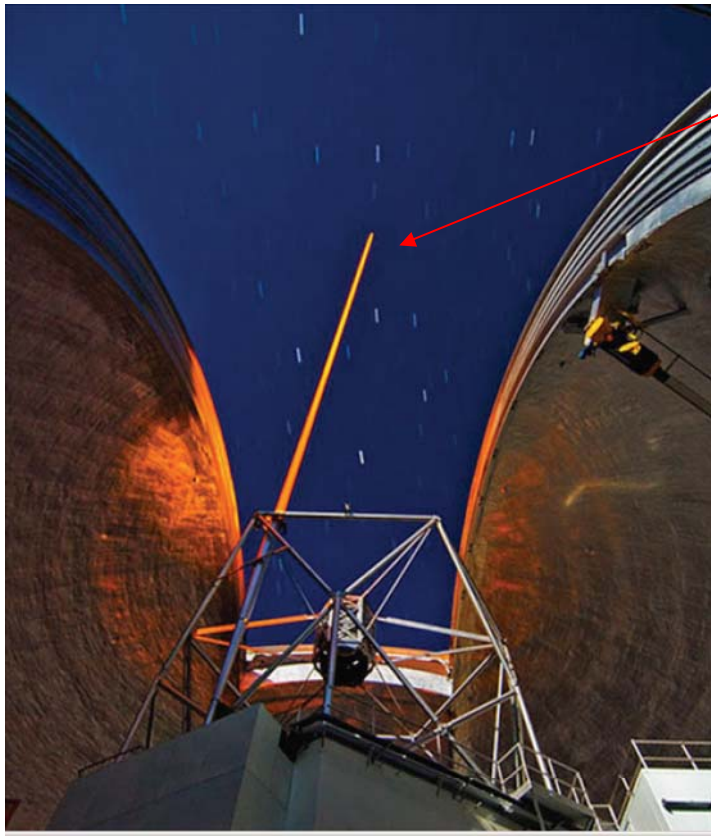
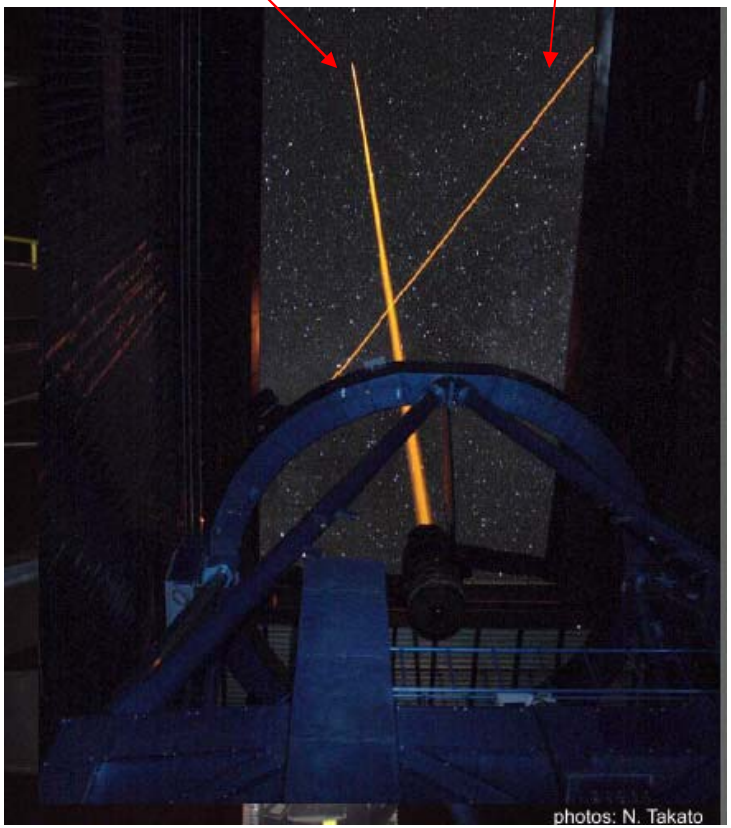
Other LGS Systems





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B. Wide-Field Adaptive Optics

There are 3 solutions under development

- MCAO – Multi-conjugate AO
- GLAO – Ground Layer
- MOAO – Multi-object AO

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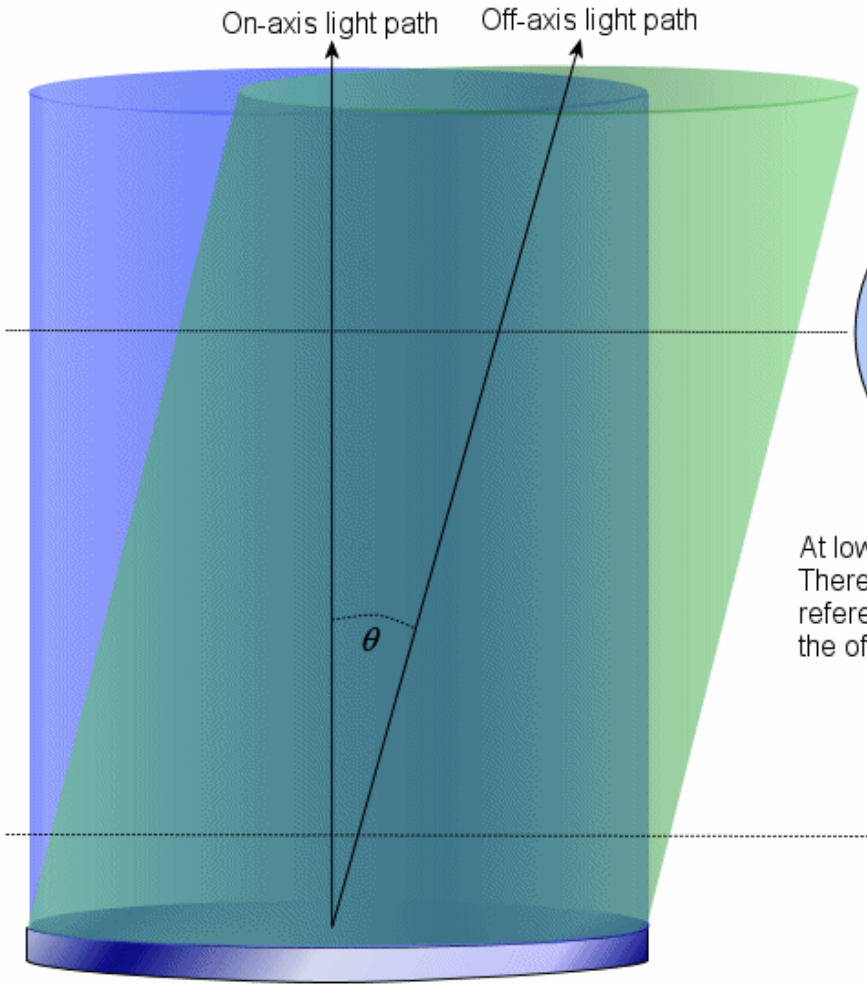
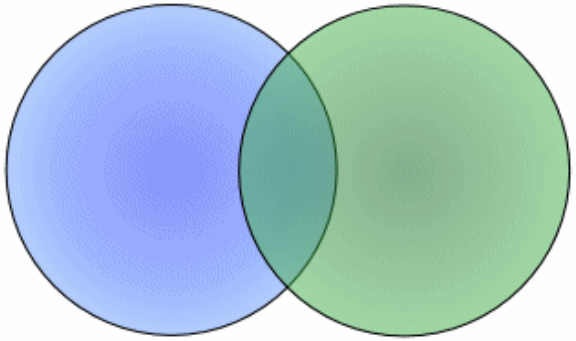
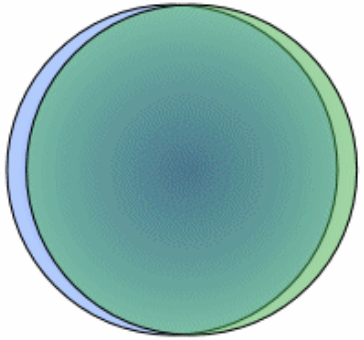
Angular Anisoplanatism



At high altitudes, paths sample separate atmospheres. There is a large wavefront variance between on and off-axis beams.



At low altitude, on and off-axis paths overlap. Therefore a correction applied to the on-axis reference path will provide a good correction to the off-axis light path irrespective of field angle, θ.



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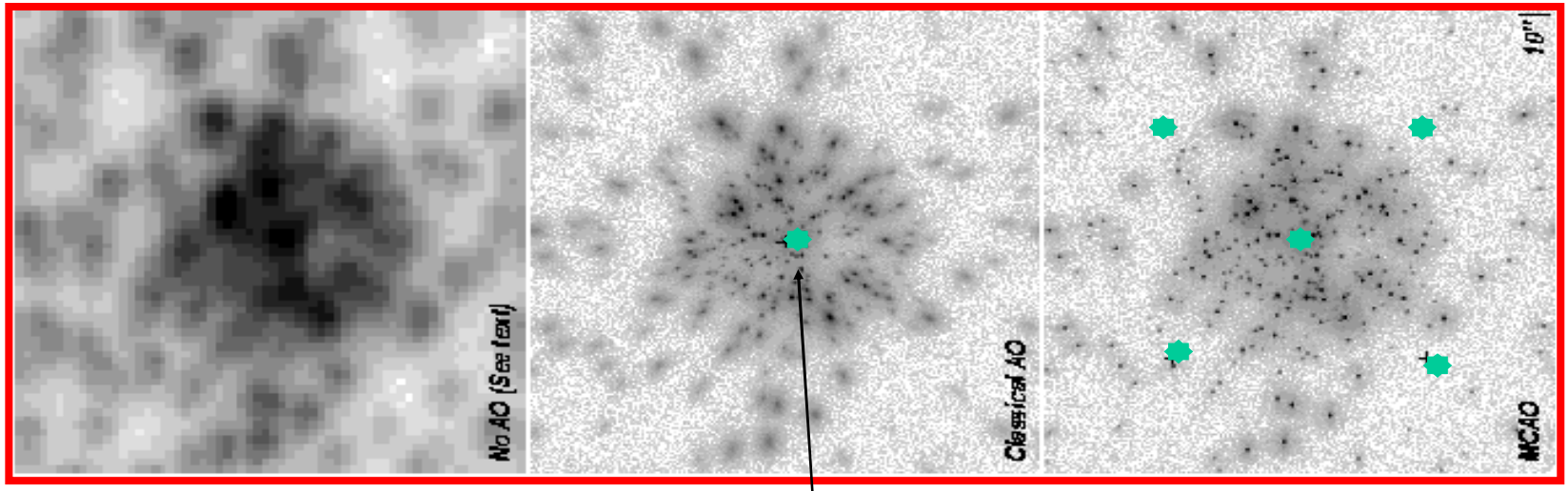
Multi-Conjugate AO

Simulation showing how correction degrades off axis, and how MCAO can correct this.

No AO | Classical AO | MCAO



LGS

Star sizes are magnified, and f.o.v ~ 2'

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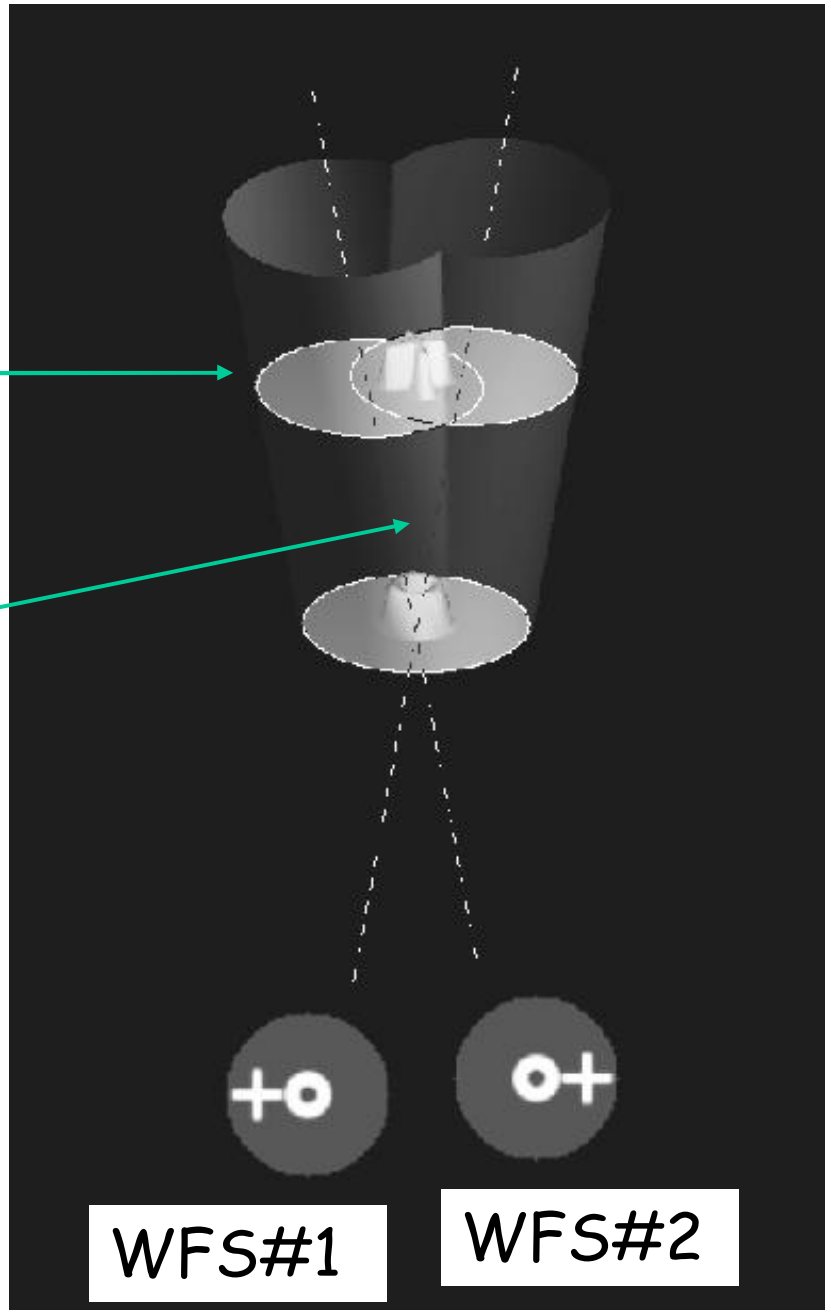
Courtesy of GEMINI

Tomography

Altitude Layer
(phase aberration = +)

Ground Layer = Pupil
(phase aberration = O)



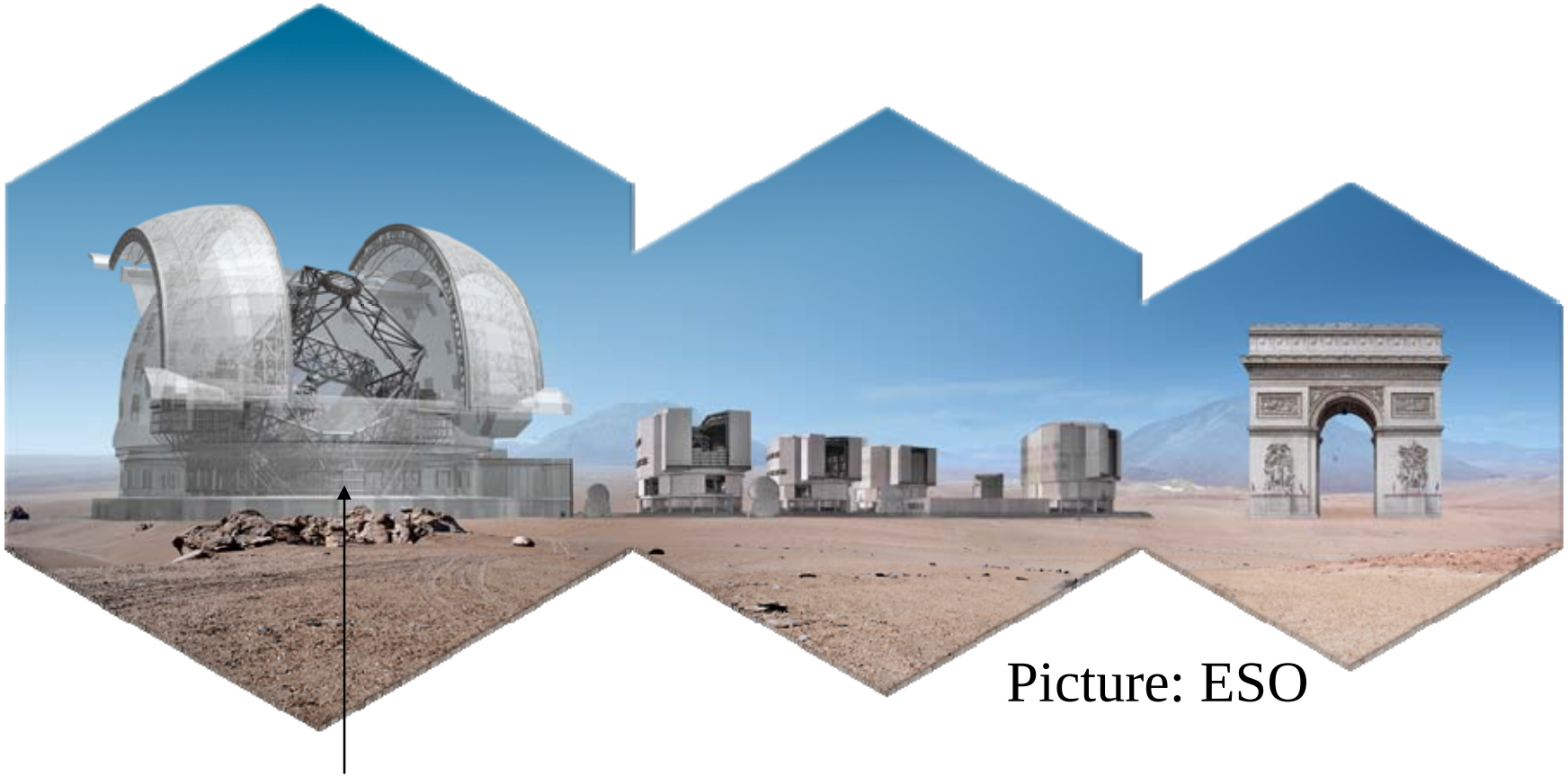
Courtesy of F. Rigaut,Gemini

C. Extreme AO (XAO)

- In theory – this is the same as conventional AO – but with "more of everything"
  - More actuators in the DM
  - More wavefront sensing elements

- Current generation of AO systems have ~10^2 actuators.
- Visible AO requires 10^3 - 10^4

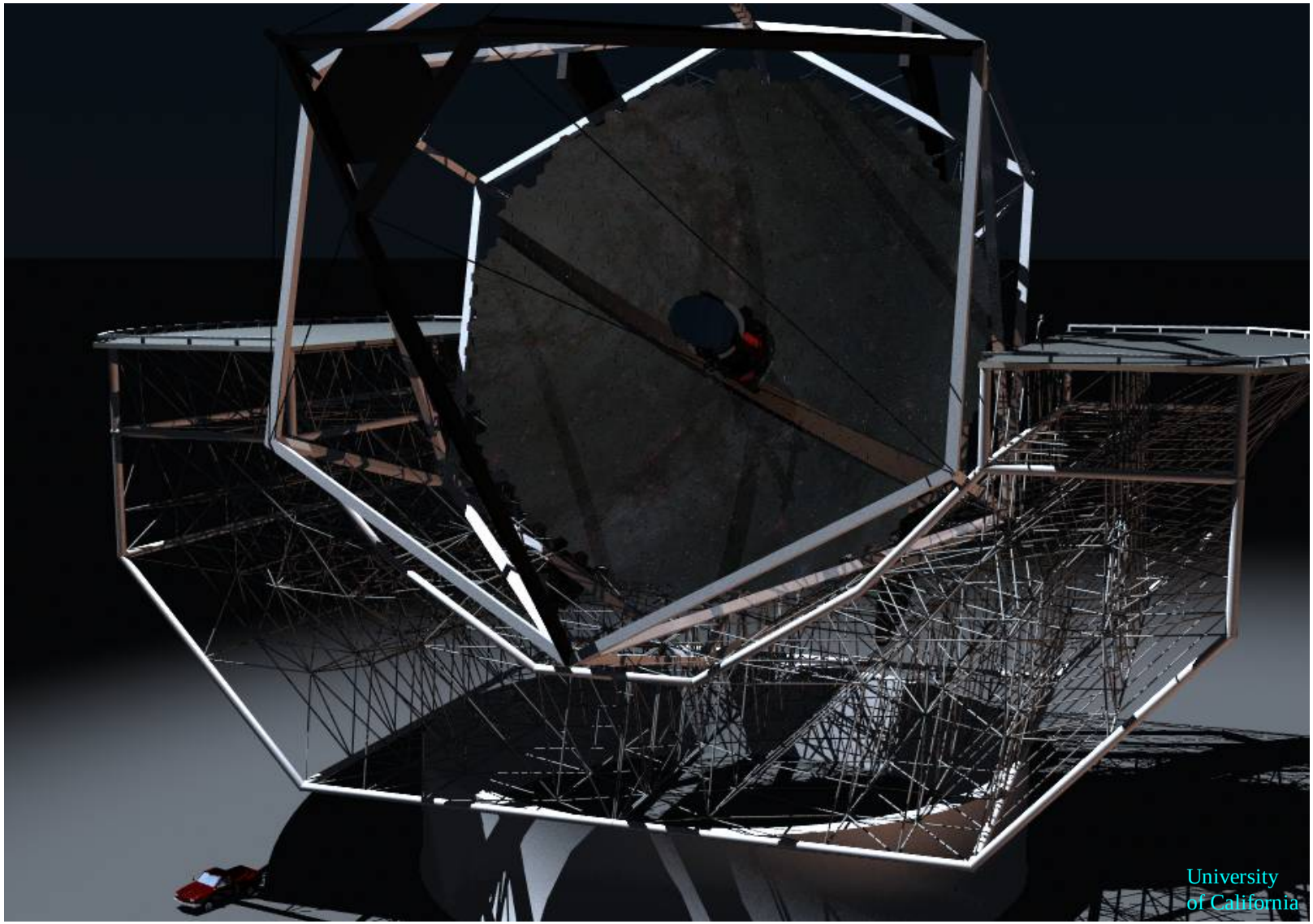
- E.g. A 42m ELT (extremely large telescope) requires ~$(D/r_0)^2$ ~$(42/0.15)^2$ ~10^5 actuators.



Picture: ESO

The European Extremely Large Telescope (E-ELT) is being designed with a 42-metre primary mirror -and will be the first telescope with AO built-in: telescope mirror 4 will be a deformable mirror with over 5000 actuators.

TMT – 30m (USA)



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Non-Astronomical (and Non-Military) Applications of Adaptive Optics

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Other Applications

OPHTHALMIC OPTICS

- Retinal Imaging
- Optometry

LASERS

- High power laser spot control
- Optical storage
- Optical Communications

IMAGING

- Consumer optics

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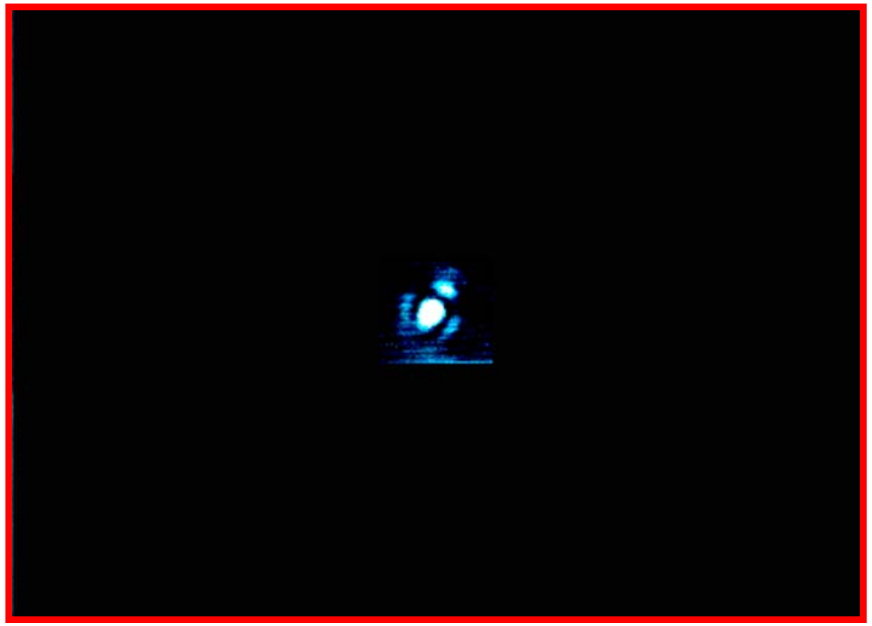
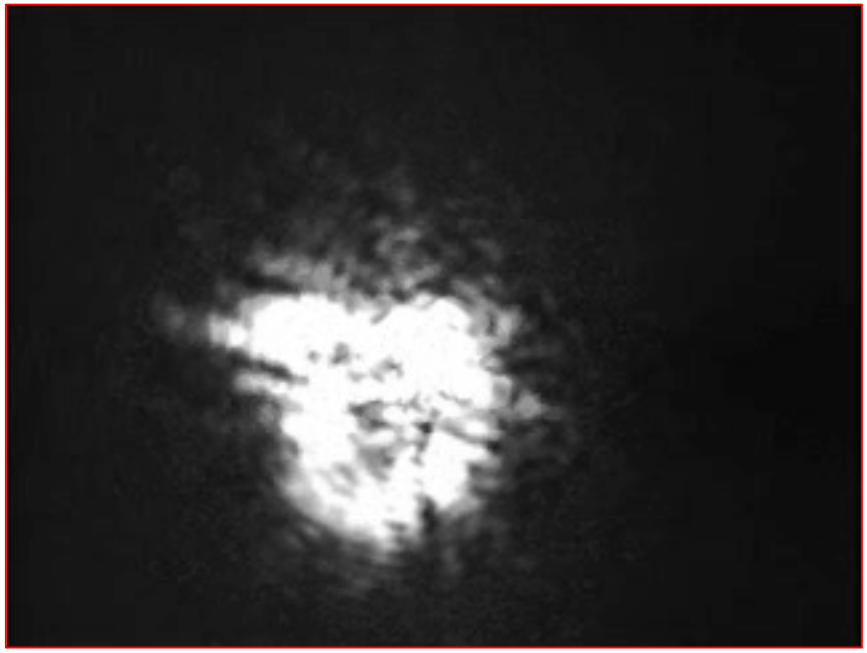
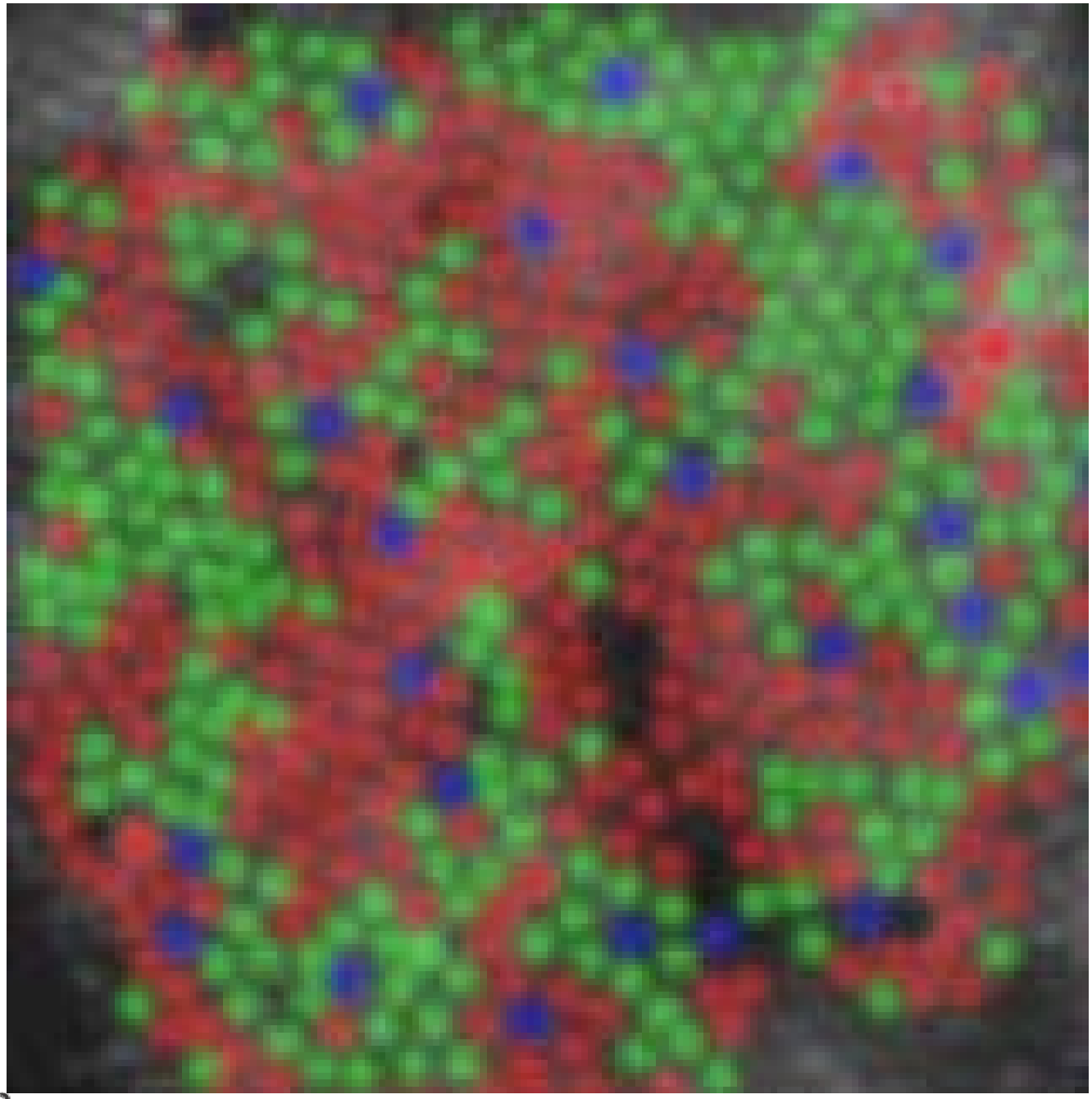
E.g. Optical Communications



E.g. – 100m propagation path length at Durham





(Courtesy of David Williams, Rochester)

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Fig. 1

The quick brown fox jumps over the lazy dogs

Fig. 2

Fig. 3

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Wavefront Control

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Adaptive Spectacles

(Courtesy of Joshua Silver, Oxford)

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Conclusions

- Astronomical AO is maturing and most observatories now have common-user systems
- We are working towards…
  - Full sky AO
  - Visible AO
  - Wide field AO
  - AO for Extremely Large Telescopes
- AO is being exploited in other areas of optics (e.g. ophthalmology) but exploitation also involves the exploitation of individual parts of a system - rather than the whole