The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2018-25

Winter College on Optics in Environmental Science

2 - 18 February 2009

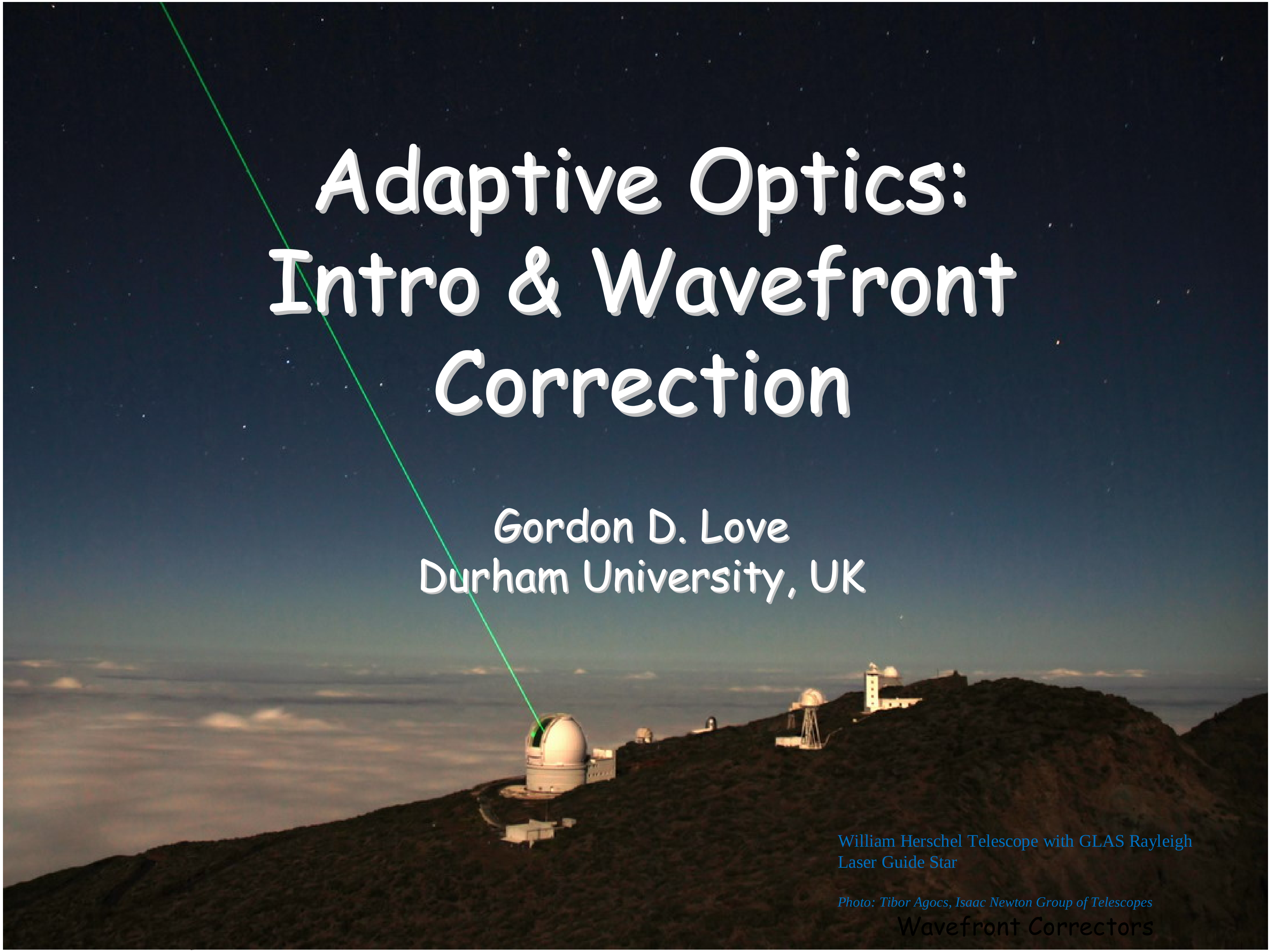
Adaptive Optics: Introduction, and Wavefront Correction

Love G.

University of Durham
U.K.

Adaptive Optics: Intro & Wavefront Correction

Gordon D. Love
Durham University, UK



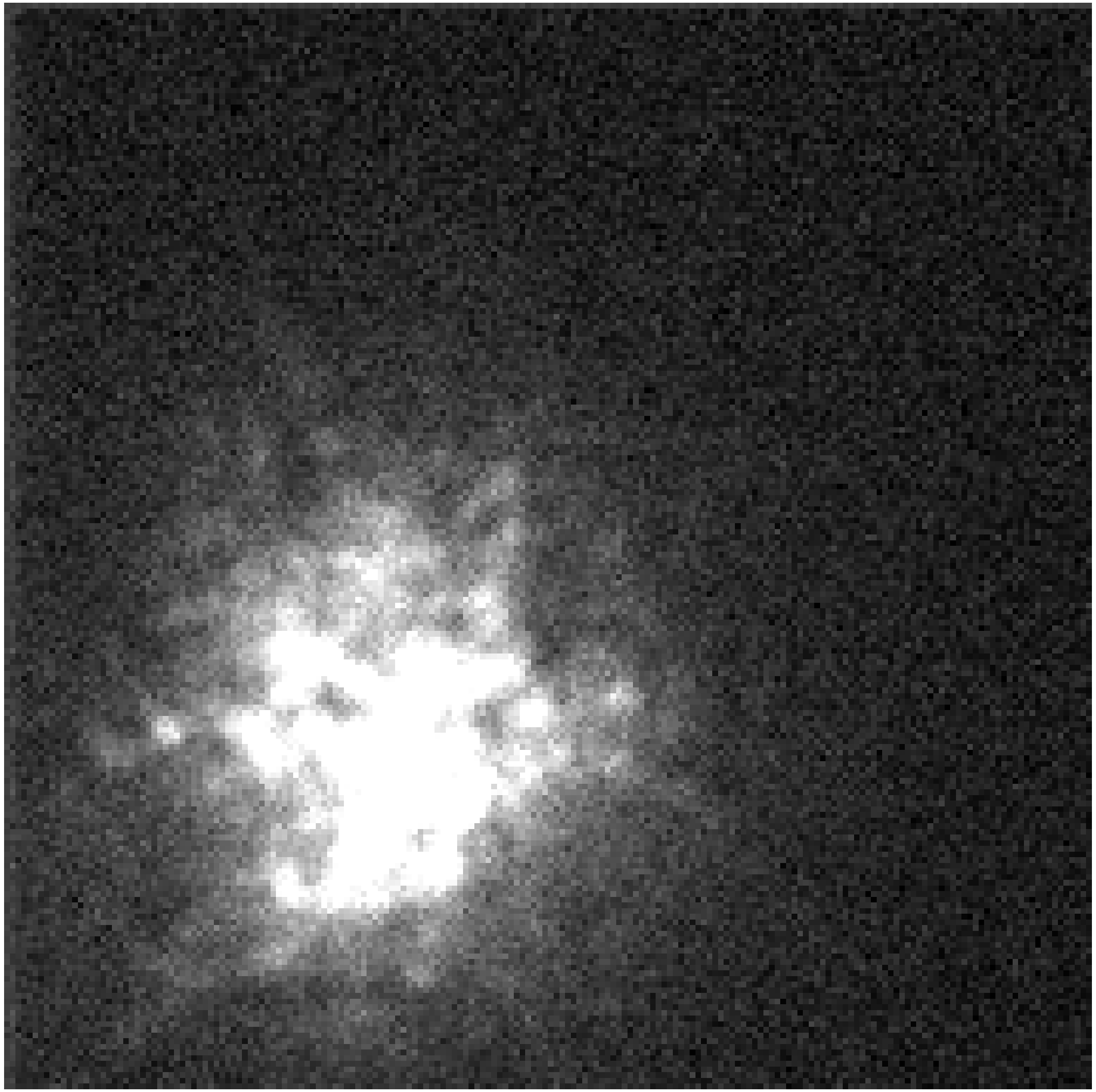
William Herschel Telescope with GLAS Rayleigh Laser Guide Star

Photo: Tibor Agocs, Isaac Newton Group of Telescopes

Overview

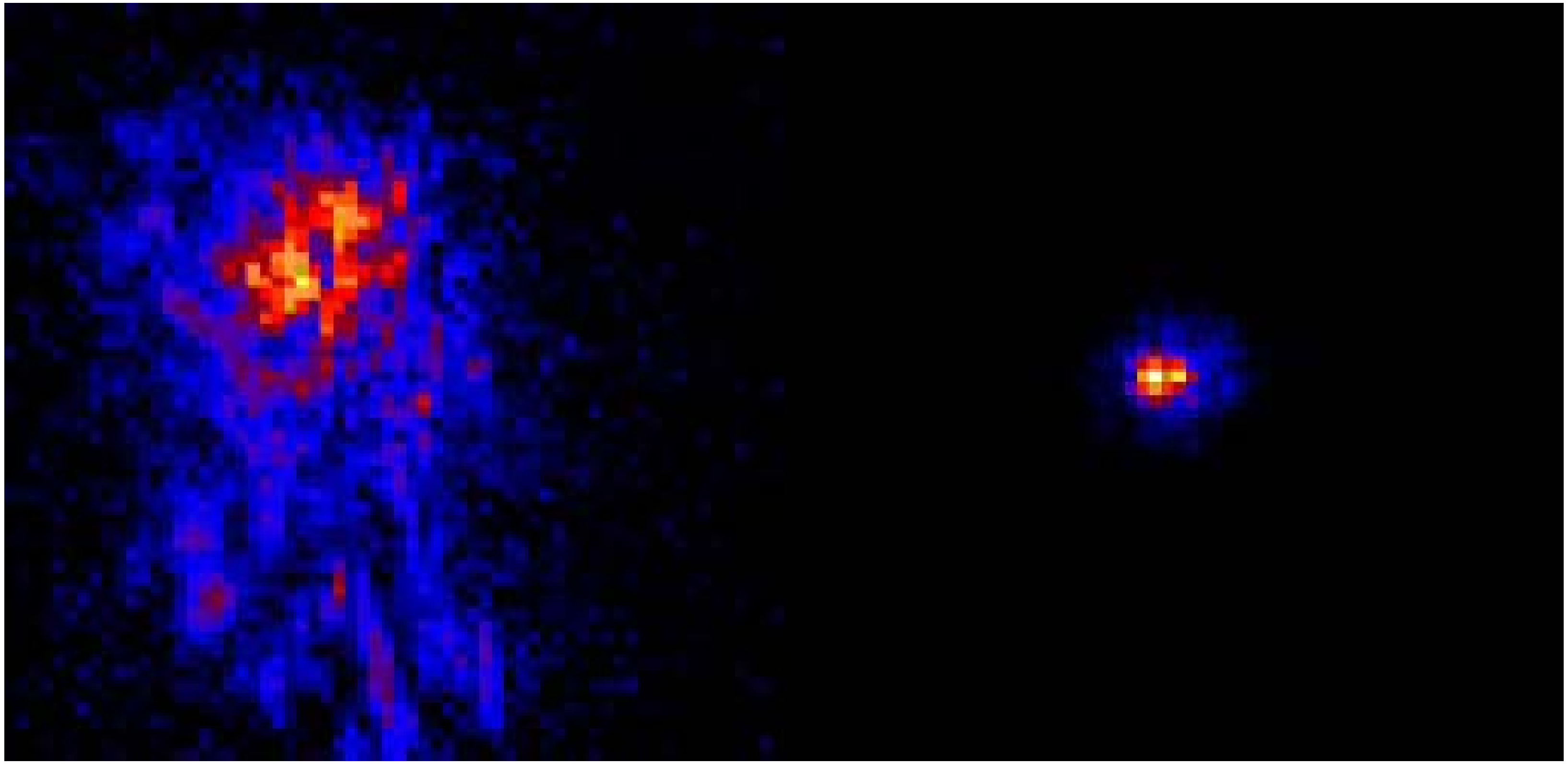
- Lecture 1: Intro & Wavefront Correction
- Lecture 2: Wavefront Sensing
- Lecture 3: Systems and Applications

Atmospheric Seeing



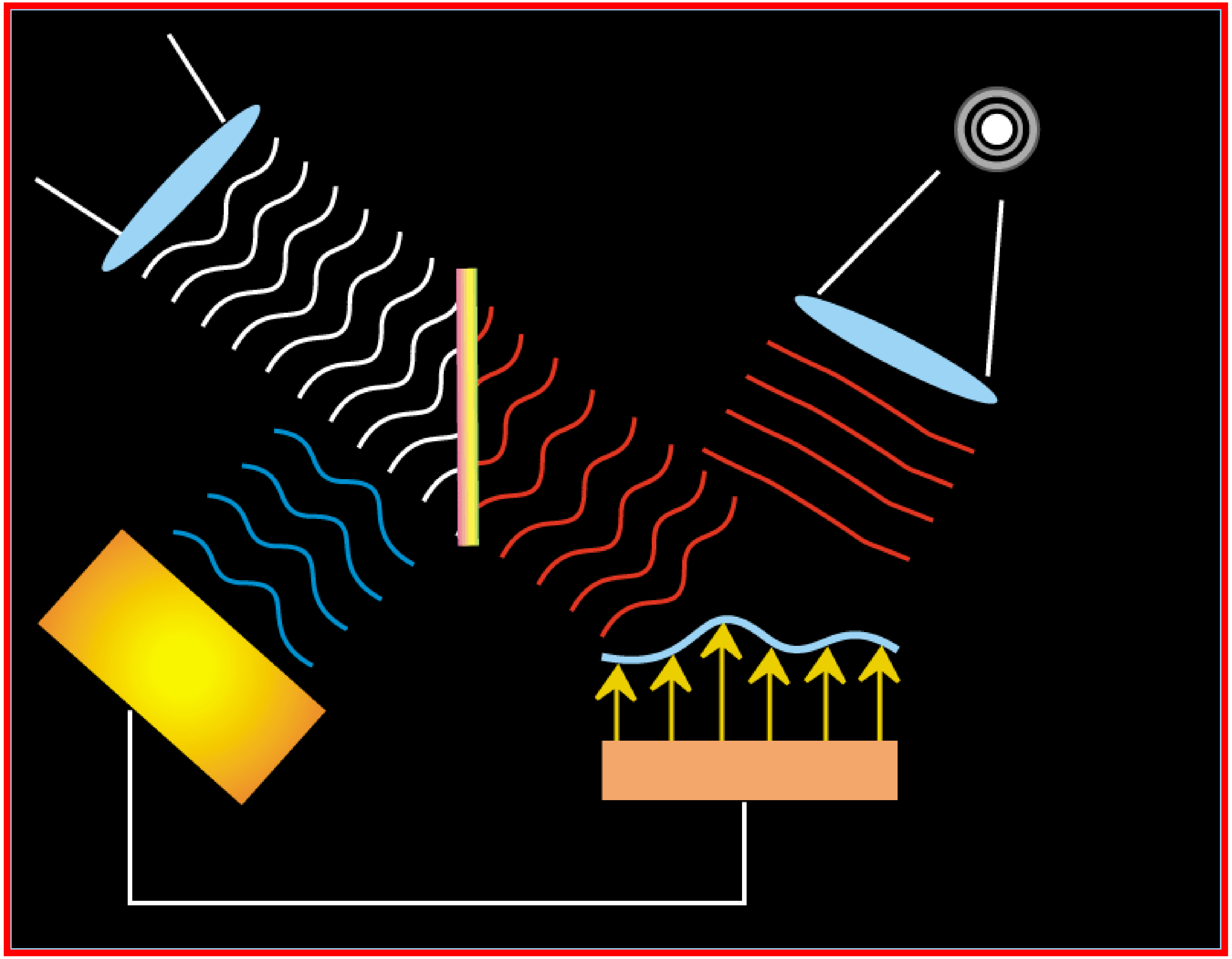
Durham University

Courtesy of
http://cfao.ucolick.org/



Durham University

Adaptive Optics: Overview



Durham University

Atmospheric Seeing

Atmospheric turbulence causes two main effects on telescope images…

1. Resolution is degraded (by a factor of ~ D/r_0)

$$resolution \propto 1.22\, \lambda / r_0$$

2. Intensity is degraded by a factor of about

   ~ $(D/r_0)^2$.

Durham University

Adaptive Optics (AO)

Real-time correction of wavefront distortion

Differs from *Active Optics* (aO) by convention:

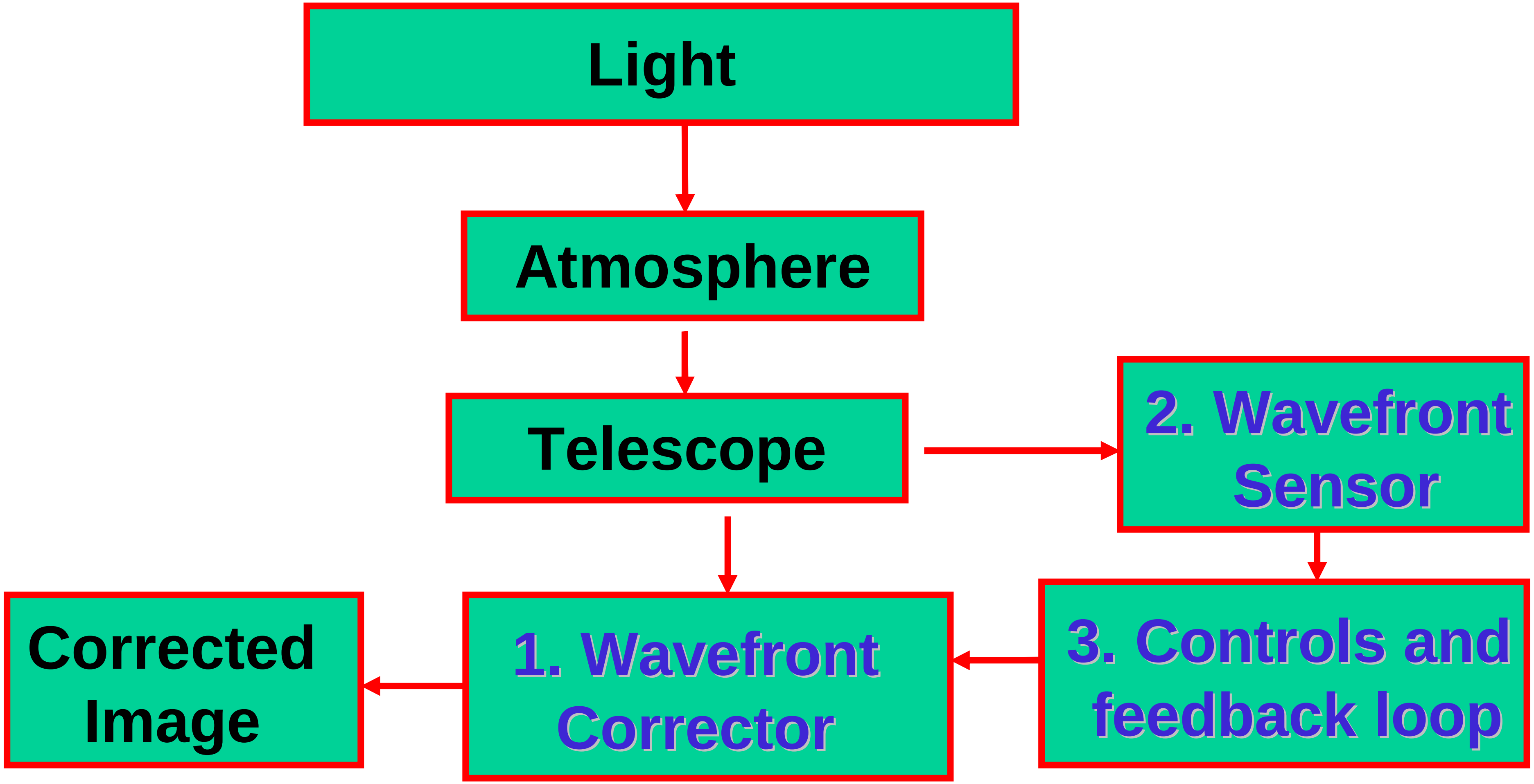
- Active Optics deals with aberrations < 10Hz
  - Gravitational flexure of primary and mechanical support structures
  - Generally includes actuation of the primary itself
- Adaptive Optics deals with > 10Hz
  - Atmospheric turbulence, fast wind-shake
  - Generally performs phase correction at a de-magnified pupil or turbulence image

Durham University

Methods for image compensation

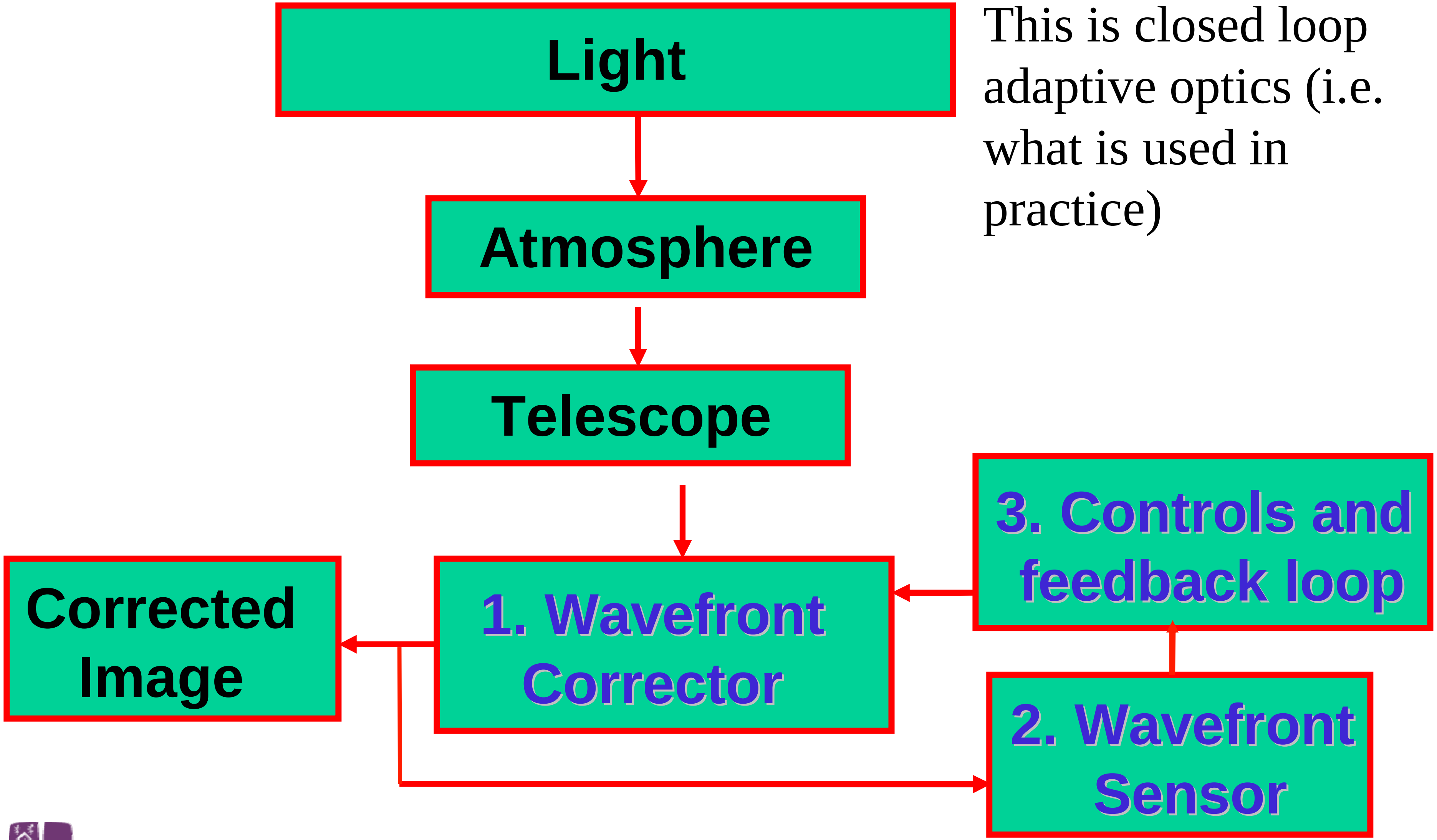
1. Go to Space
   - HST - Great! But expensive.
   - NGST - Requires some image correction, anyway.
2. Post-exposure sharpening
   - deconvolution
   - no hardware required.
   - no improvement in SNR.
   - Can't feed light into a spectrograph
3. Phase conjugation
   - Needs bright source and reference wave
4. Adaptive optics
   - Real time correction
   - Improvement of SNR + resolution

Adaptive Optics - 3 Basic Components



This is open loop adaptive optics

Adaptive Optics - 3 Basic Components



This is closed loop adaptive optics (i.e. what is used in practice)

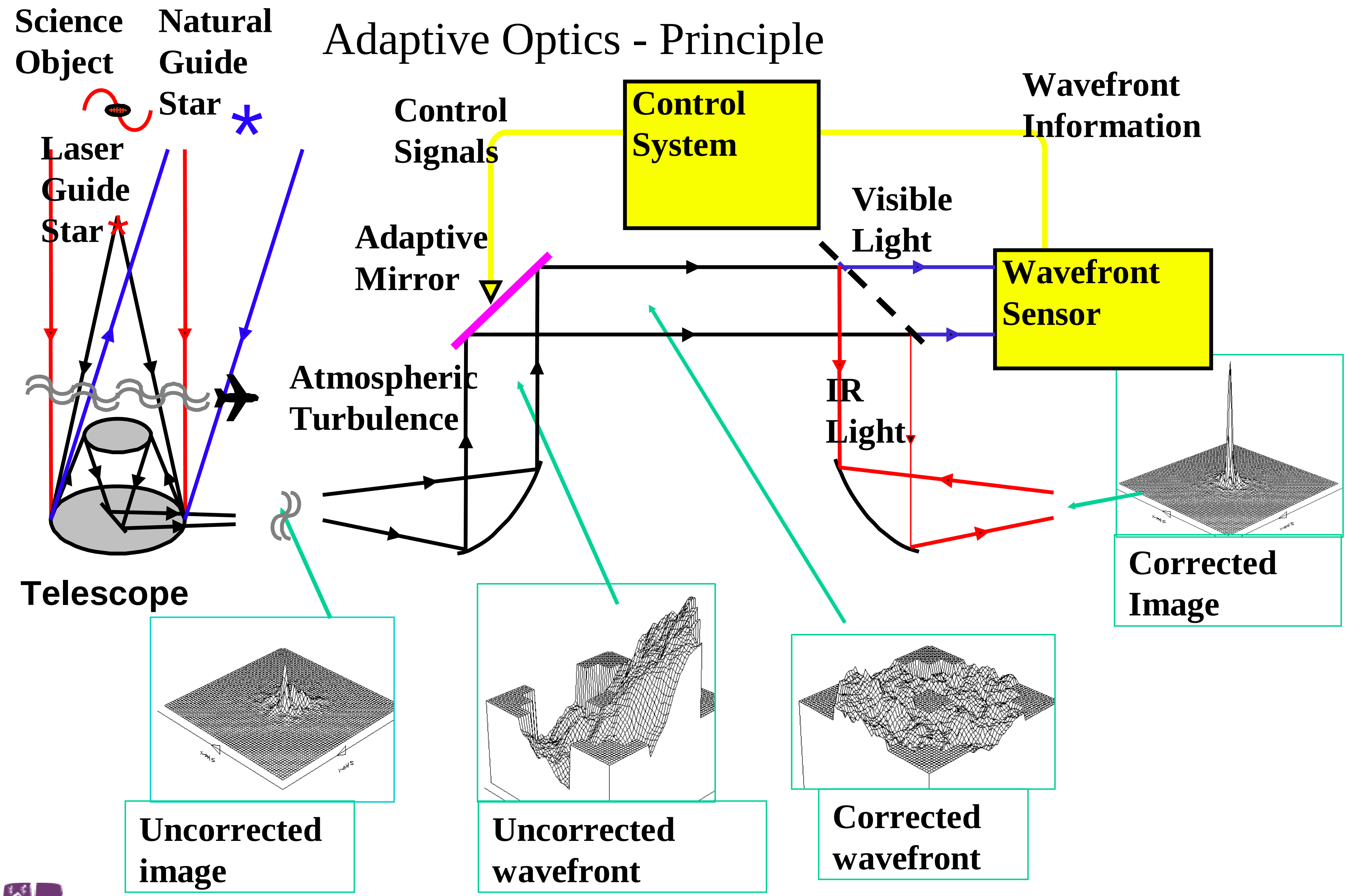
Durham University

Adaptive Optics - Principle

- An adaptive optics system contains all the classic components of a feedback loop -
  - a controller, or corrector
  - a sensor
  - feedback loop
- Other Control Loop Systems
  - toilet cistern (v. simple)
  - thermostat+ heating system,
  - car cruise control
  - adaptive sound reduction

Durham University

Adaptive Optics - Principle



Durham University

Wavefront Correction

- Overview of Wavefront Corrector (WFC) technology
  - Deformable Mirrors
  - Liquid crystal technology

- Currently available technology
- Future technology

Overview of Wavefront Corrector Technology

A WFC must be able to control OPTICAL PATH LENGTH.

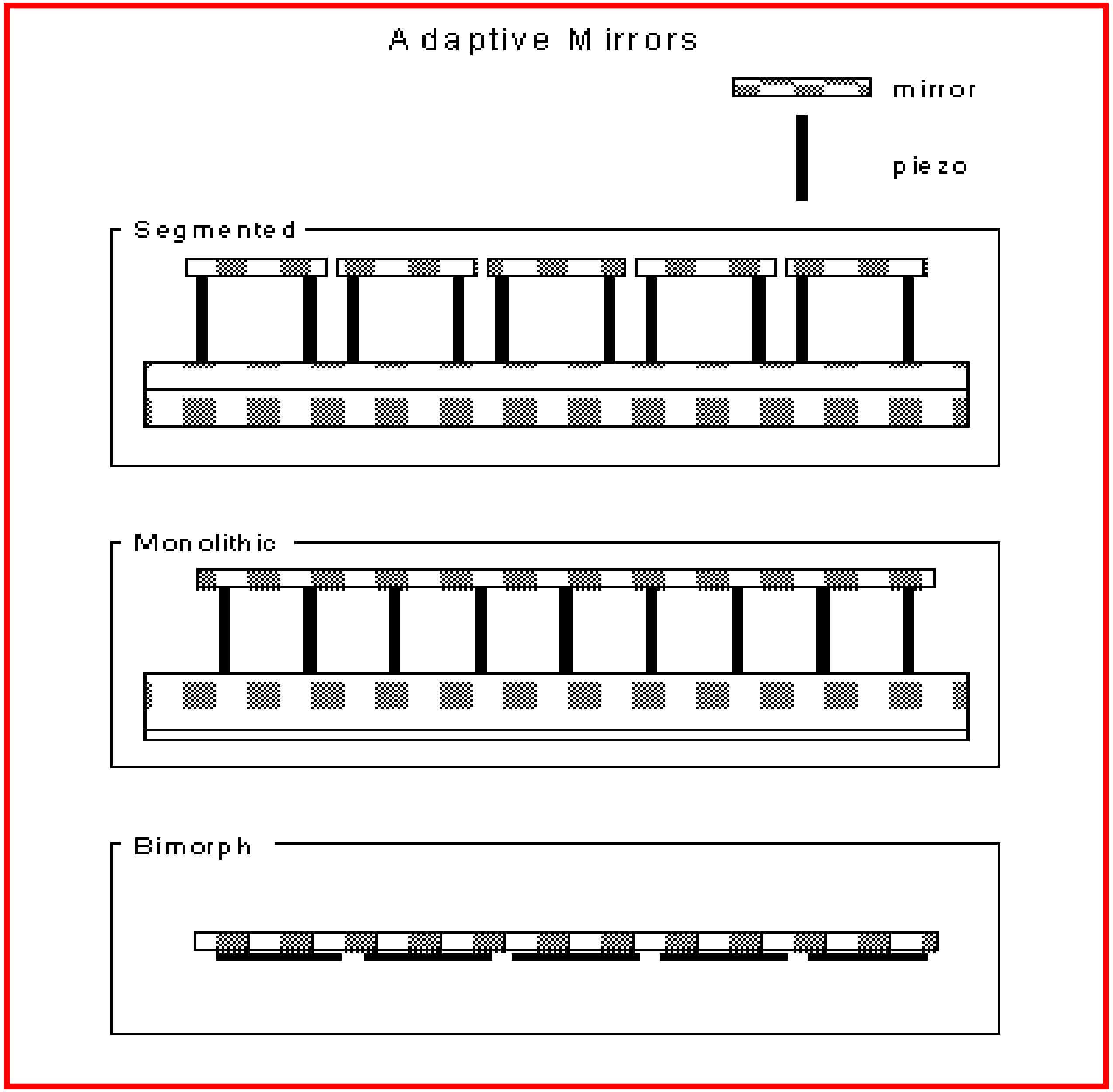
- Optical path length is defined as refractive index x distance.
- Thus, we can either control the real path length and keep the refractive index fixed (use a mirror) or do the opposite and modulate the refractive index (liquid crystal).

Durham University

DEFORMABLE MIRRORS (DMs)

There are a whole range of DMs which can be classified in different ways…

1. By the structure of the mirror
   - Continuous Facesheet Mirrors
   - Segmented Mirrors
2. By the actuator technology
   - PZT: Piezoelectric actuators
   - PMN: Electrostrictive Materials
   - Voice Coils
   - Electromagnetic Attraction
3. By the mirror structure
   - Stacked Actuator
   - Bimorphs
   - MEMS

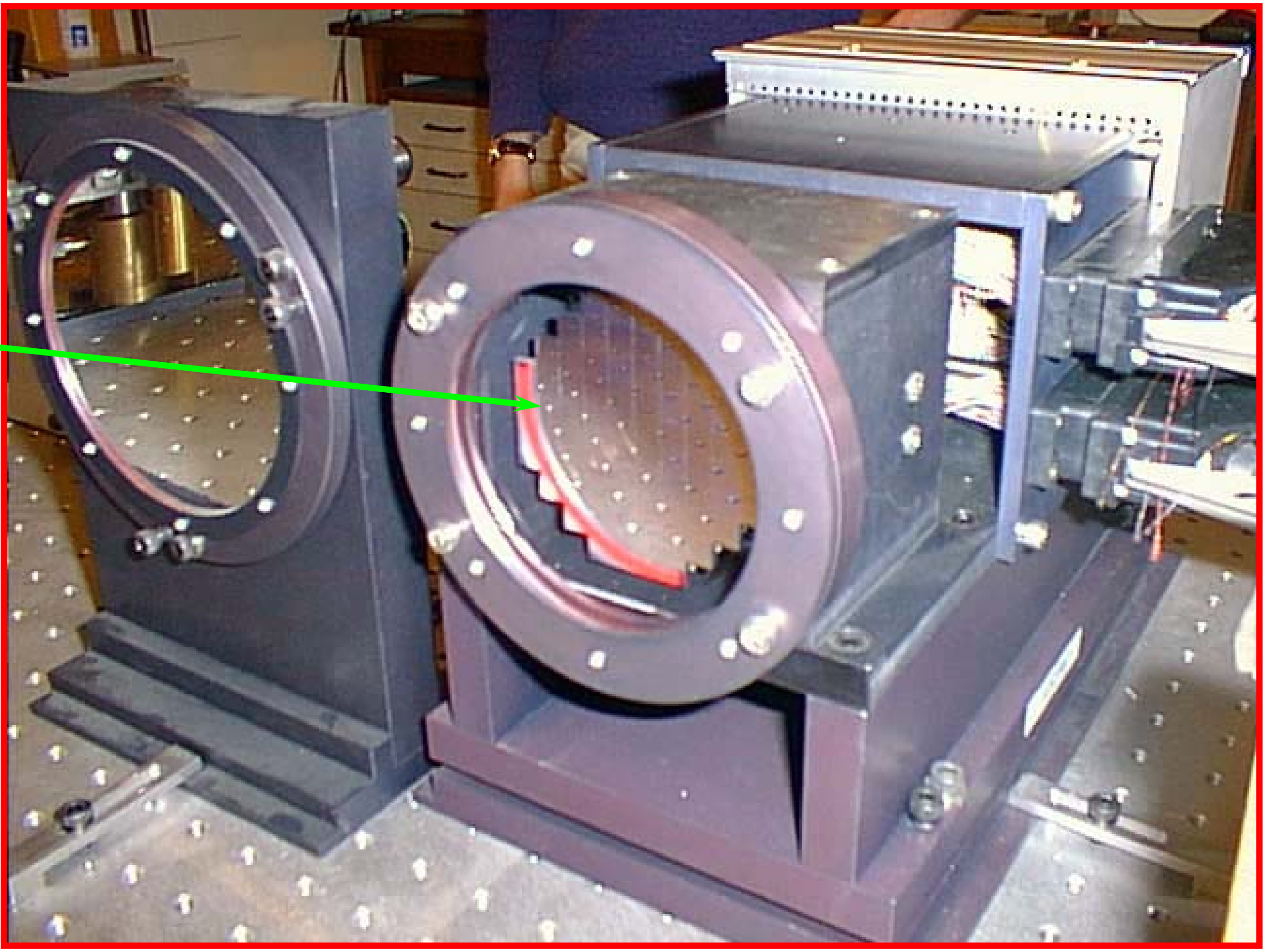


Types of Adaptive Mirror

Durham University

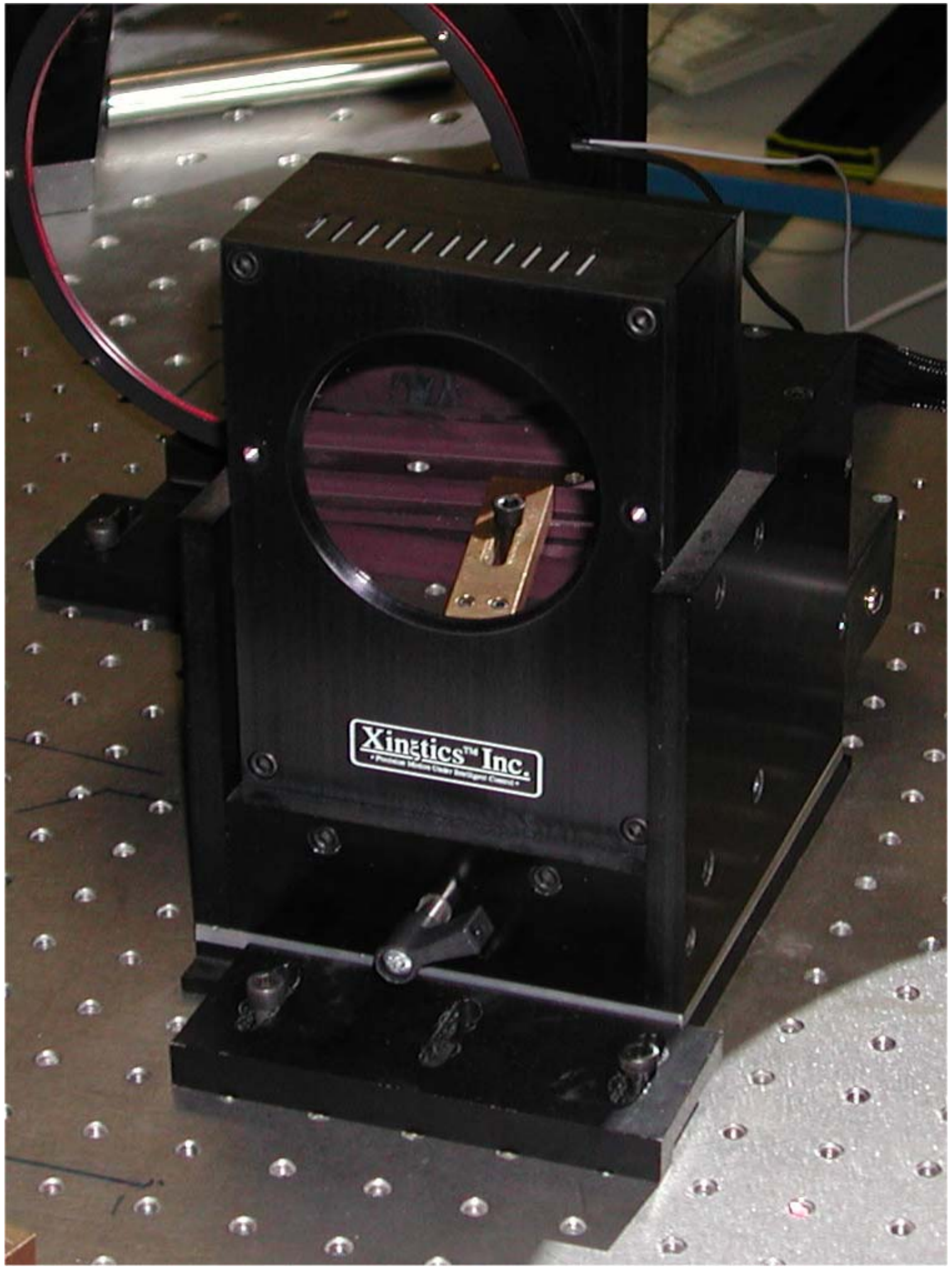
. The ELECTRA Segmented Adaptive Mirror (76 tip-tilt-piston segments) built by ThermoTrex, San Diego

228 degree of freedom adaptive mirror



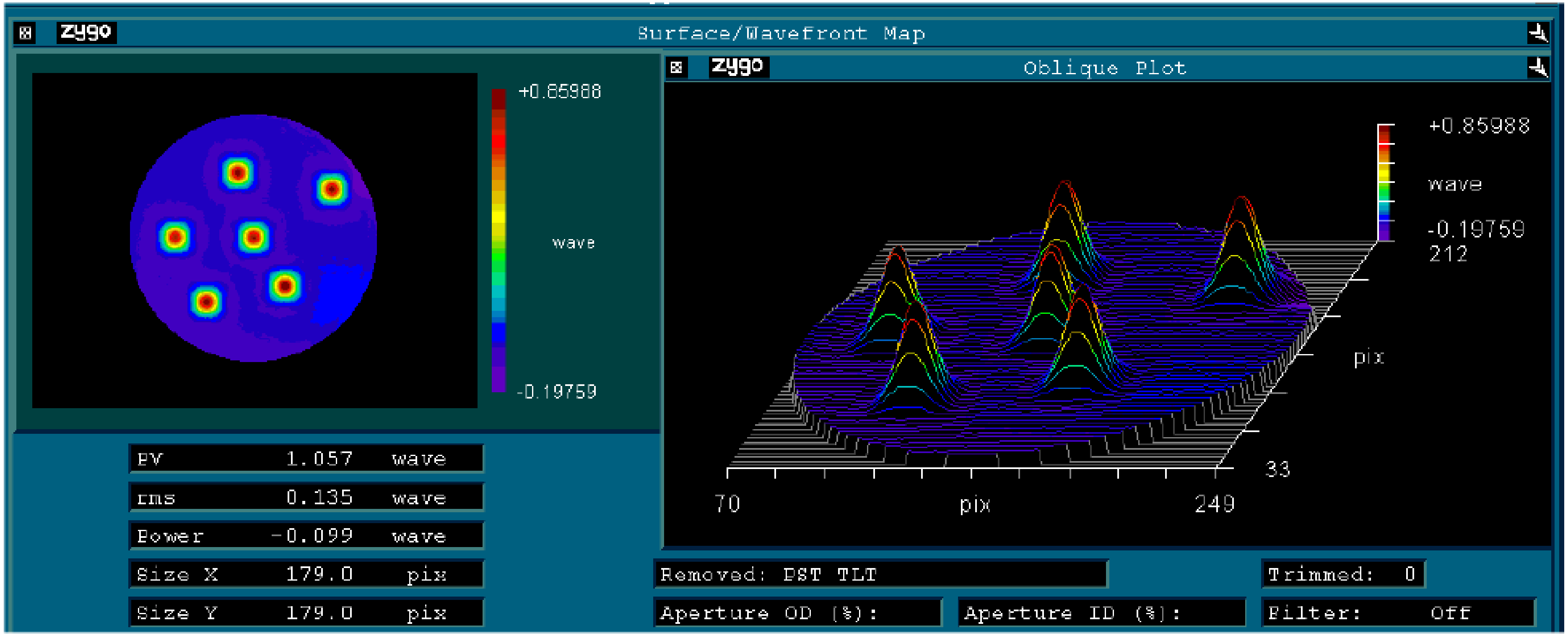
. Xinetics DMs

- "Standard" products include DMs varying from 37 to 941 actuators.
- Continuous facesheet DMs based on PMN technology.



Xinetics DMs

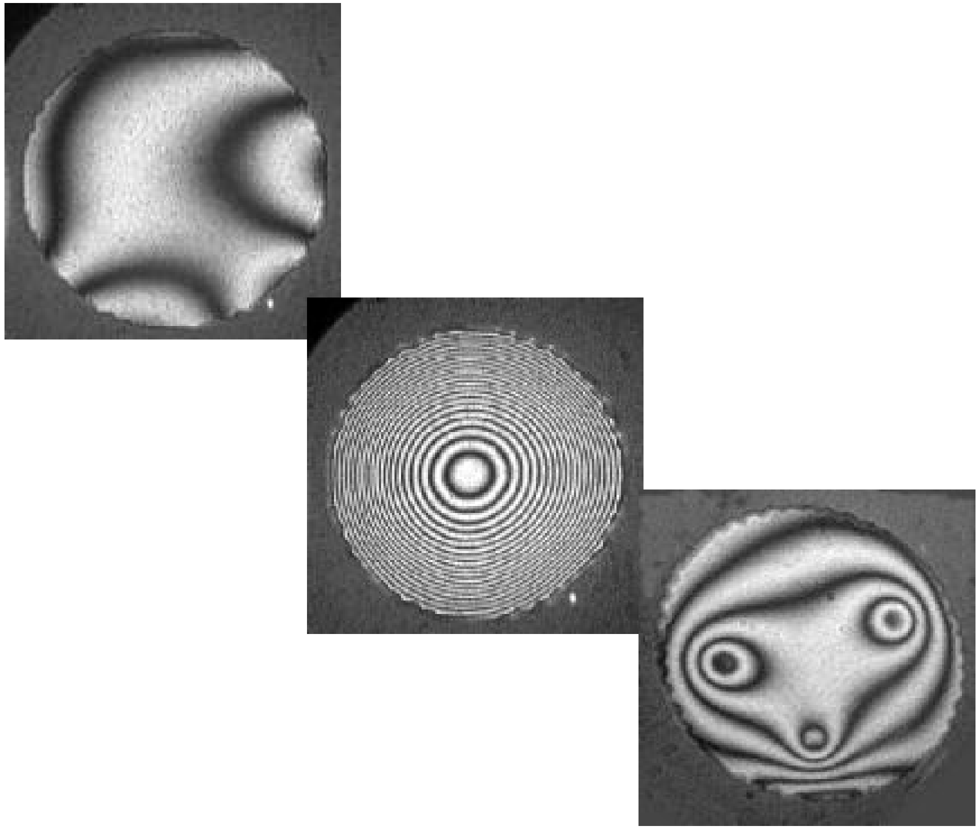
Example "poke" interferogram from a 177 actuator device (GEMINI DM). Courtesy of Xinetics



Durham University

FlexibleOptical Mirror

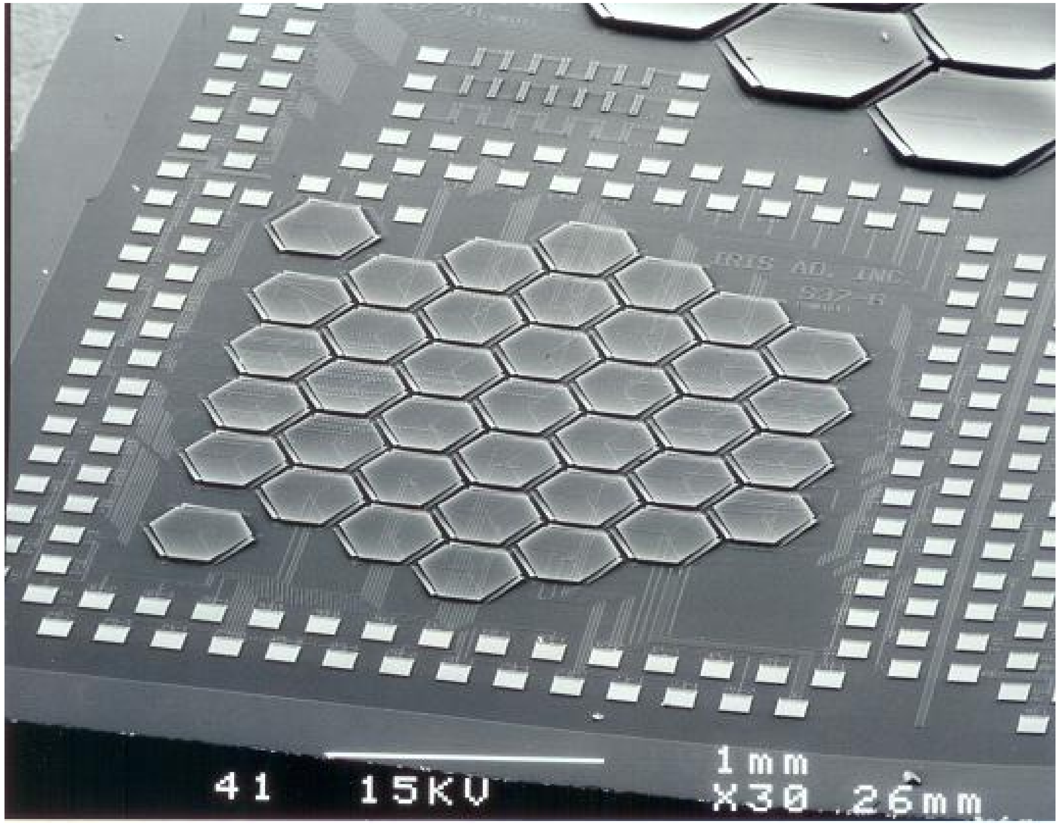
- Membrane mirror
- Produced by Flexible Optical (Delft, NL)



Durham University

IRIS AO

- MEMS Technology



Deformable Secondaries

- MMT, Steward Observatory. 336 actuator device
- Advantage: Reduced emissivity and scattering

LIQUID CRYSTAL DEVICES

1. LCs: Principle of operation.
2. Nematic LCs.
3. Ferroelectric LC turbulence generators.
4. Phase conjugation

Liquid Crystal Wavefront Controllers

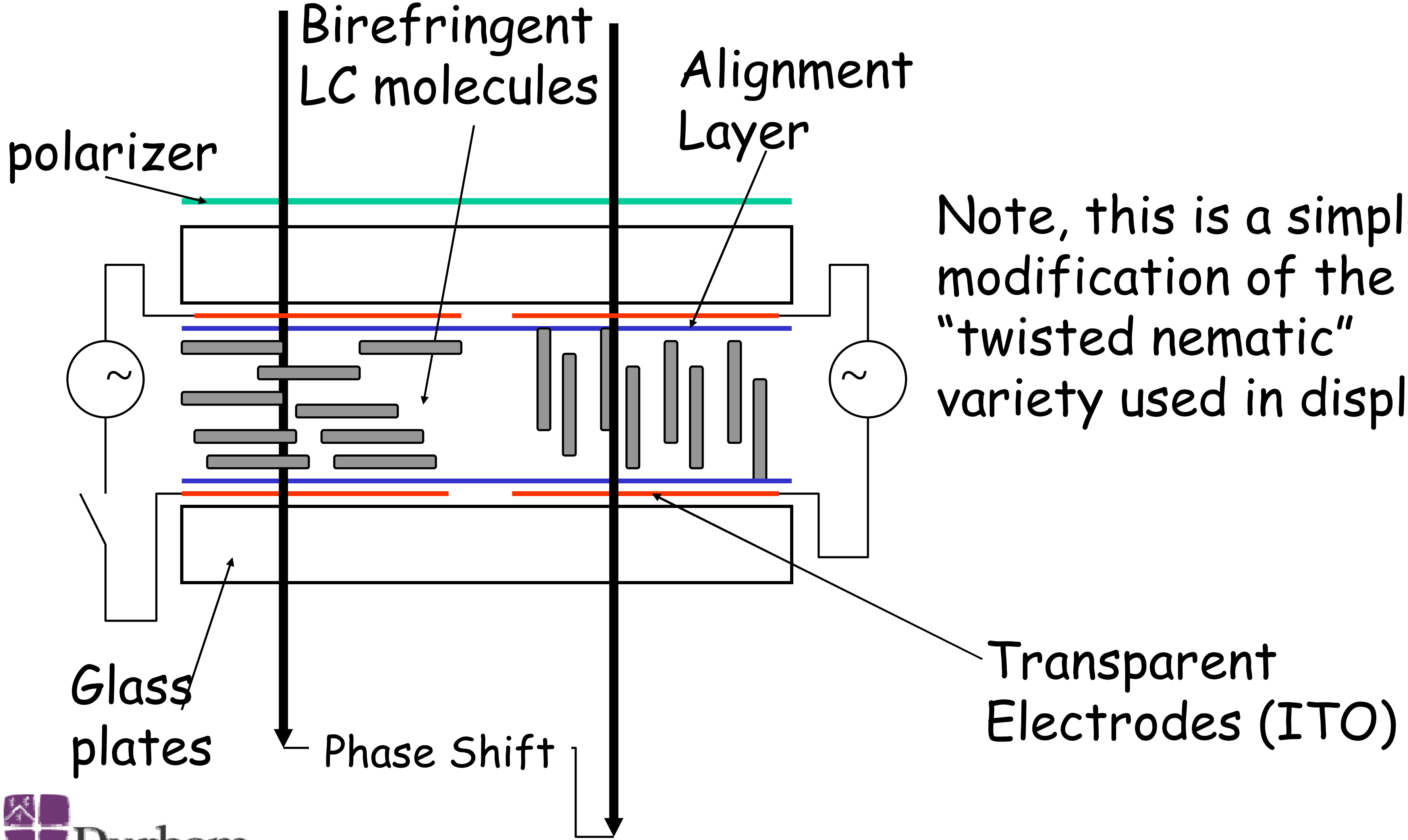
There are 2 fundamentally different types of LC which are useful in AO.

1. NEMATIC LCs

2. FERROELECTRIC LCs

Both types are electrically controllable waveplates

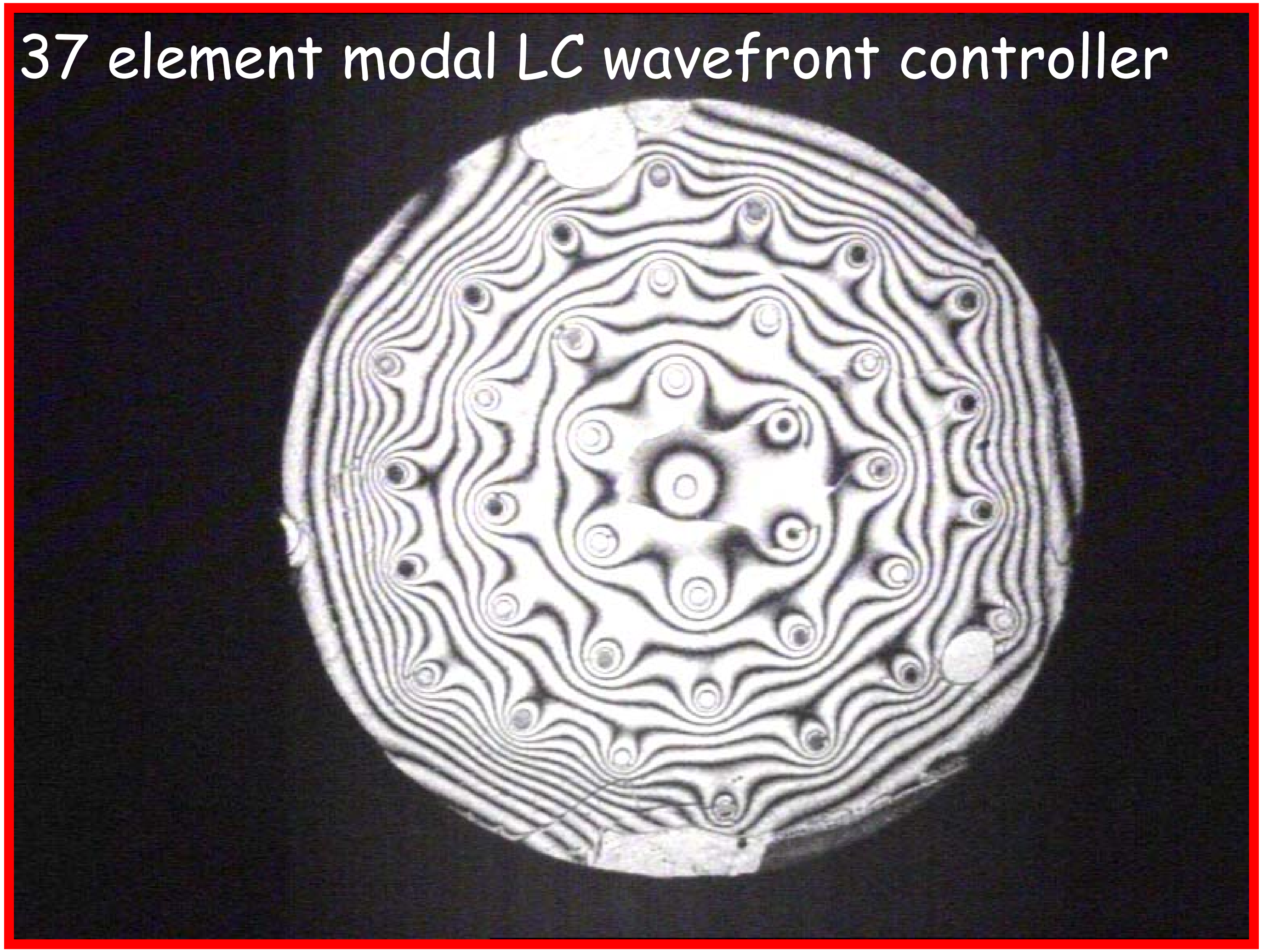
Nematic LC configured for phase modulation



Note, this is a simple modification of the "twisted nematic" variety used in displays

Durham University

Nematic LC wavefront corrector



Nematic LC Lens

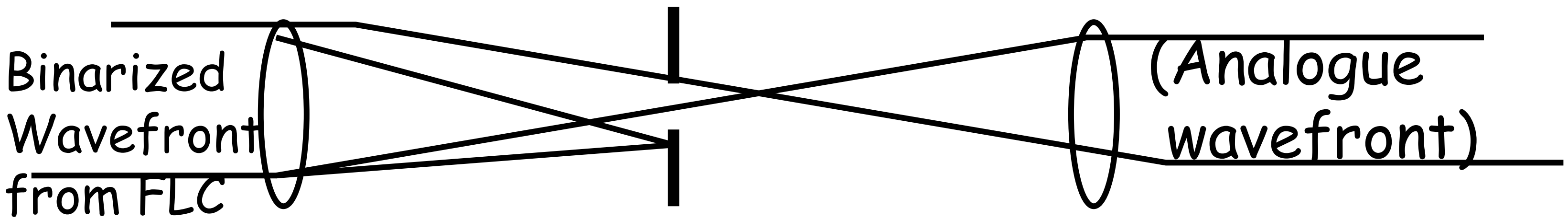
Ferroelectric LC Turbulence Generator

Because of their bistable nature, their use in AO has been limited up to now. However, by using a holographic technique, they can be used as low-cost, high performance turbulence generators (or as wavefront correctors where throughput is not an issue.)

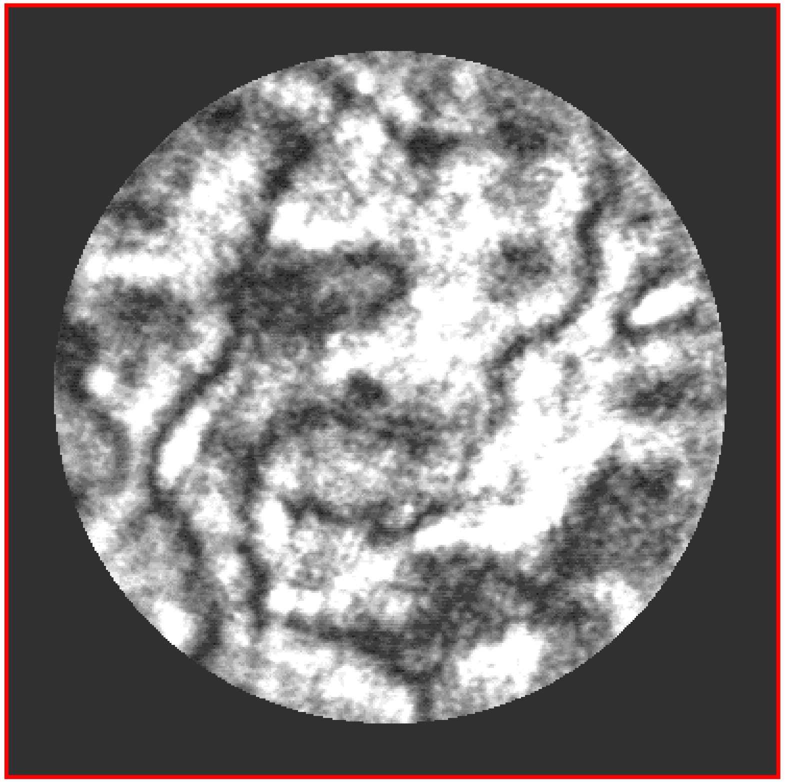
Neil *et al*. Opt. Lett. **23**(23):1849 (1998).

Ferroelectric LC Turbulence Generator

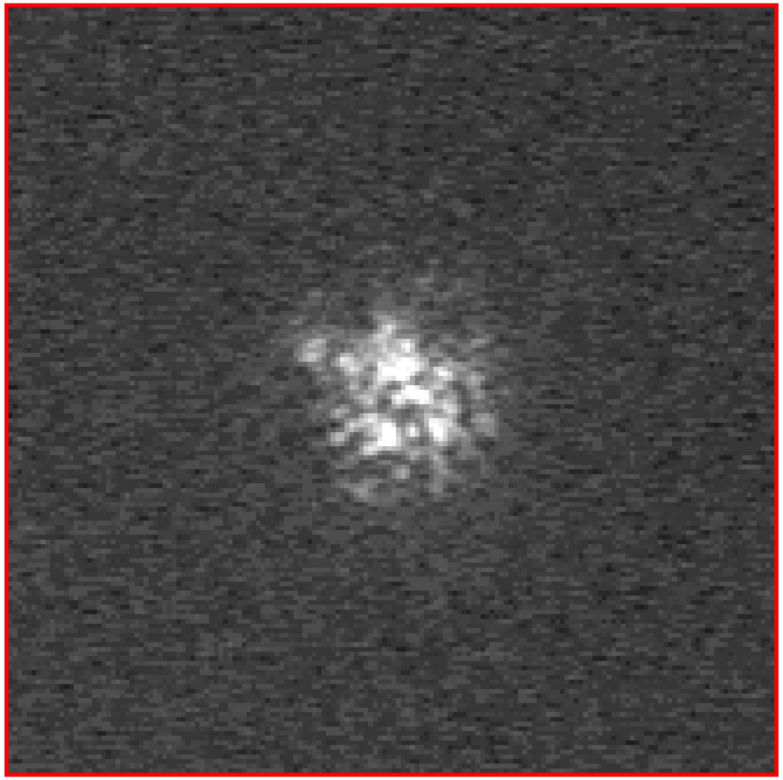
- Generate desired wavefront (in computer)
- Add a large tilt (~40 waves).
- Binarize resultant wavefront
  - binarized wavefront = π if ϕ (mod 2 π) > π.
  - binarized wavefront = 0 if ϕ (mod 2 π) < π.
- Apply binarized wavefront to FLC.
- Select desired order with a spatial filter.



Ferroelectric LC
Turbulence Generator



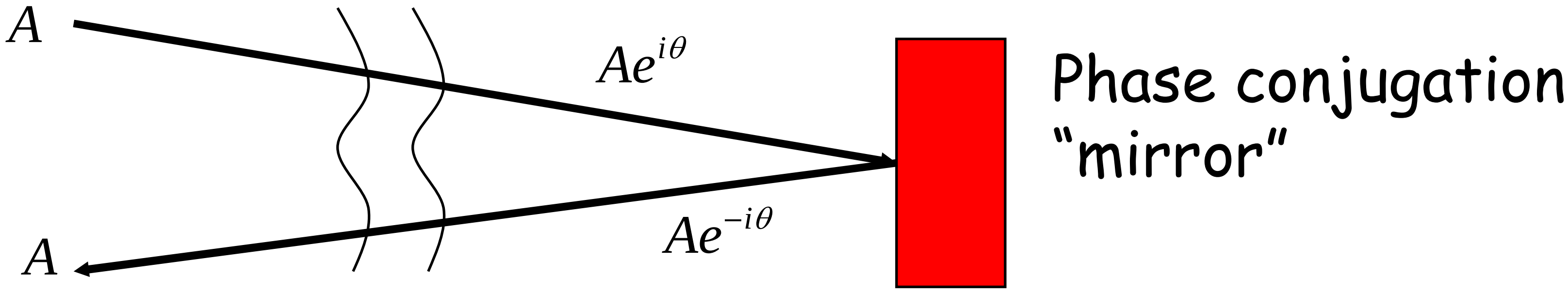
Resulting interferogram.
D/r0=13



PSF

Phase Conjugation

Phase conjugation is a technique often used in high power laser systems, and is a "parallel technology" to adaptive optics.



There exists a large body of work on using "optical addressed" liquid crystal devices as controllable diffraction gratings.

Conclusions

- Adaptive Optics is a real time technique for ameliorating the effects of aberrations on optics systems.
- Developed for imaging through atmospheric turbulence – but also applicable to other optical systems (see lecture 3).
- Wavefront correctors are critical for the precision control of