Smart Optics Technologies, Techniques and Space Applications

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Smart?

- The Smart Optics Faraday Partnership interprets ‘Smart Optics’ to mean:
  - ‘… includes optical systems, subsystems, devices and technologies that dynamically adjust …’
- Examples:
  - Adaptive optics; Programmable diffractive optics; Optically based control systems; ...

Objectives

'The ultimate aim of the Smart Optics Technology Programme is to create new, commercially successful, products based on original UK academic research in conjunction with industry and the science user base.'

smartoptics Announcement of Opportunity

Research Areas

More will said on specific project later, but work approved includes:

- Adaptive Optics Toolkit - to create a ‘plug and play’ capability in AO
- Smart Opthalmoscope - hand held high-resolution retinal imaging using sophisticated software to ‘stitch’ several images

Research Areas

- Metrology using wavefront sensing - high accuracy measurement of rough and smooth surfaces
- Liquid crystal lenses - programmable lenses using un-pixellated (modal) liquid crystal devices
- Laser marking - SMART award
- Cryogenic pick-off arms - PIPS programme

Research Areas

- CFC deformable mirrors - PIPS programme
- Consideration given to work in
  - Free-space optical communications
  - Manufacturing of large, precision optics
  - Head-mounted displays

Relevance to Space

- Smart optics is directly relevant to space projects in several ways:
  - It can lead to an ability to use light-weighted optical components
  - It can lead to enhanced performance from space-borne optical systems
  - It can lead to an ability to use reduced support structures on the satellite (thermal control)

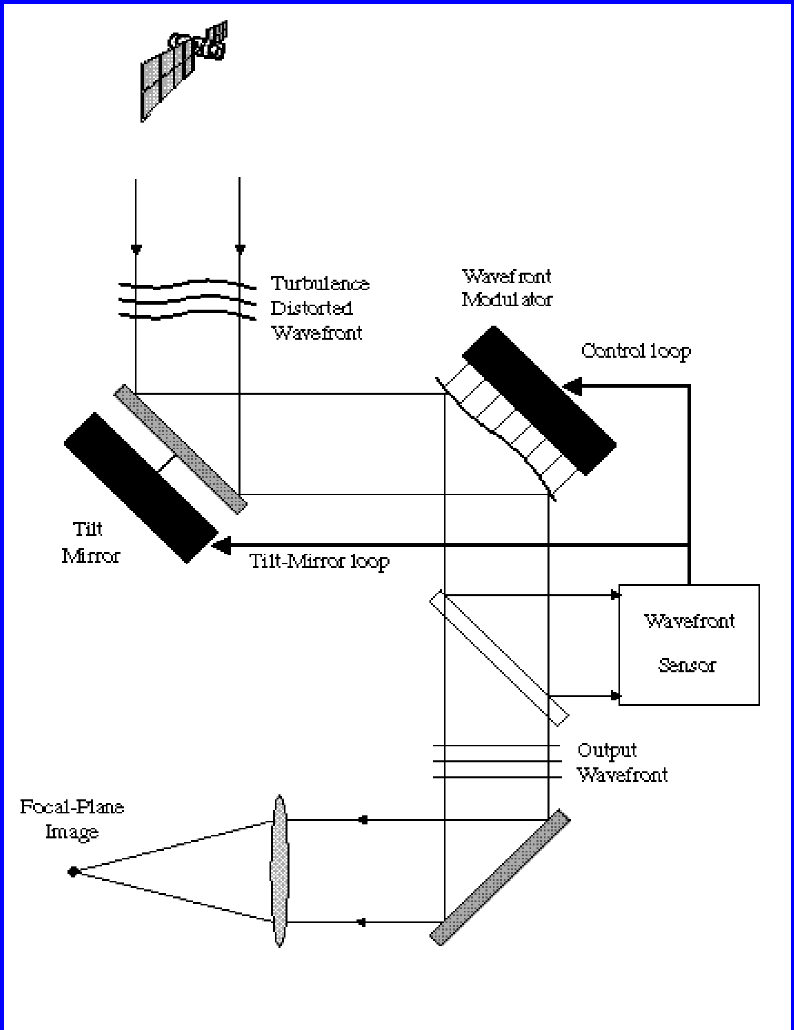
Relevance to Space

- Smart optics is indirectly relevant to space projects as well:
  - It can assist in the measurement and verification of high-performance optical systems & components
  - It can lead assist in manufacture through improvements to laser materials processing
  - Potentially, it can lead to improved signal and communication channels.

Adaptive Optics

- AO is the first thing that comes to mind when most of us think of ‘Smart Optics’
- So what is AO and does it have any relevance to space?

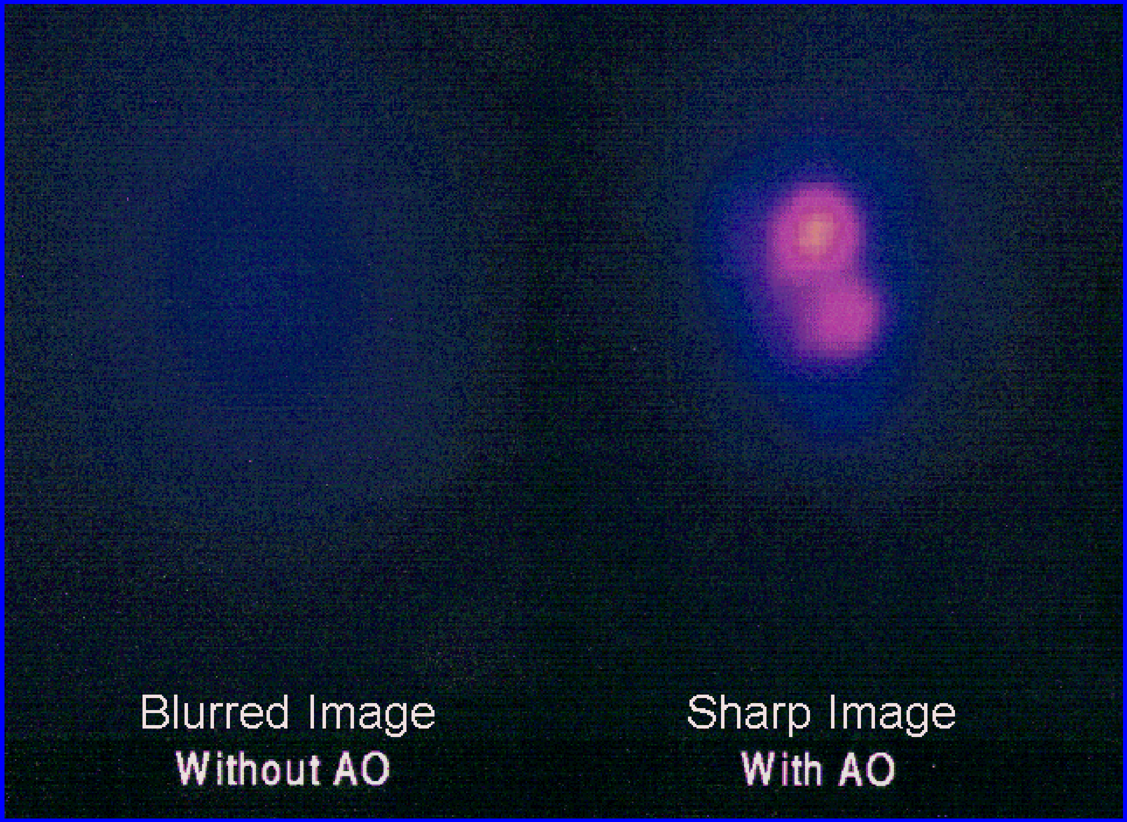
Adaptive Optics - what is it?



- **Adaptive = feedback control**
- Adaptive Optics
  - 3 Components
  - Wavefront Modulator (WFM)
  - Wavefront Sensor (WFS)
  - Control loop
- Active optics
  - No on-line control loop
  - Control signal pre-computed off-line (e.g. gravity sag, thermally-induced aberrations, ...)

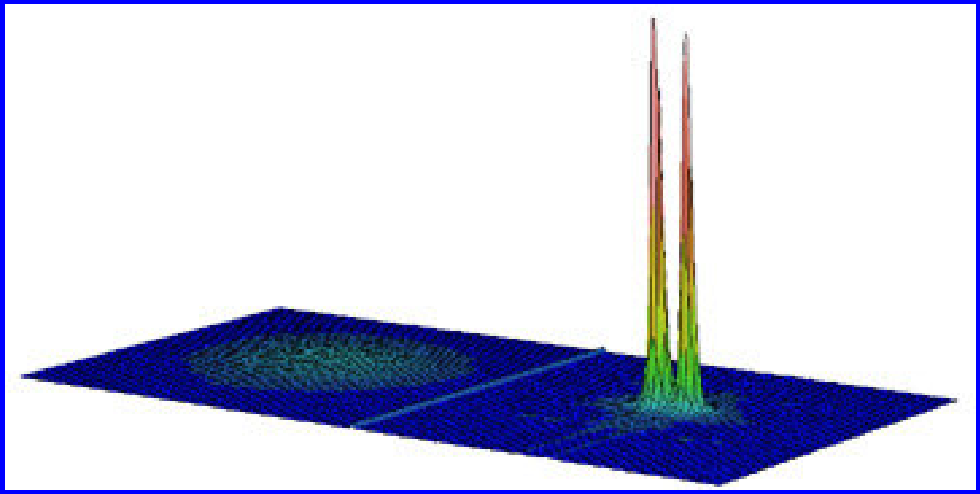
Example

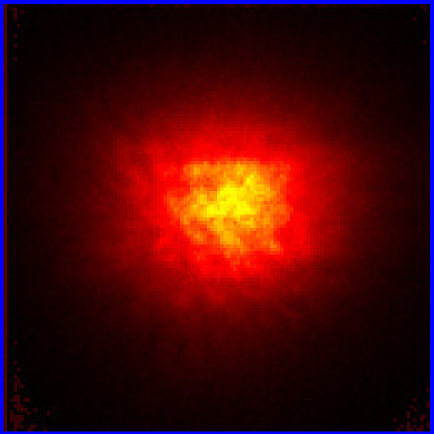
Image from CFHT at J band (1.65μm)

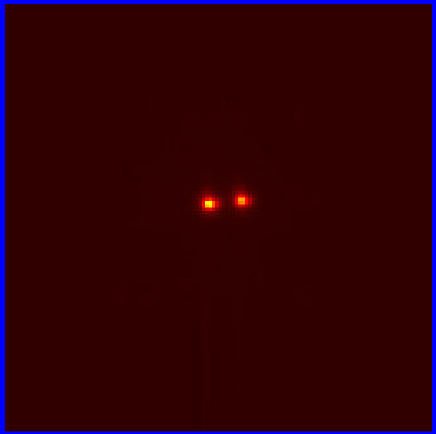


K-Peg,Starfire Optical Range

0.3 arc sec, 756 actuator mirror







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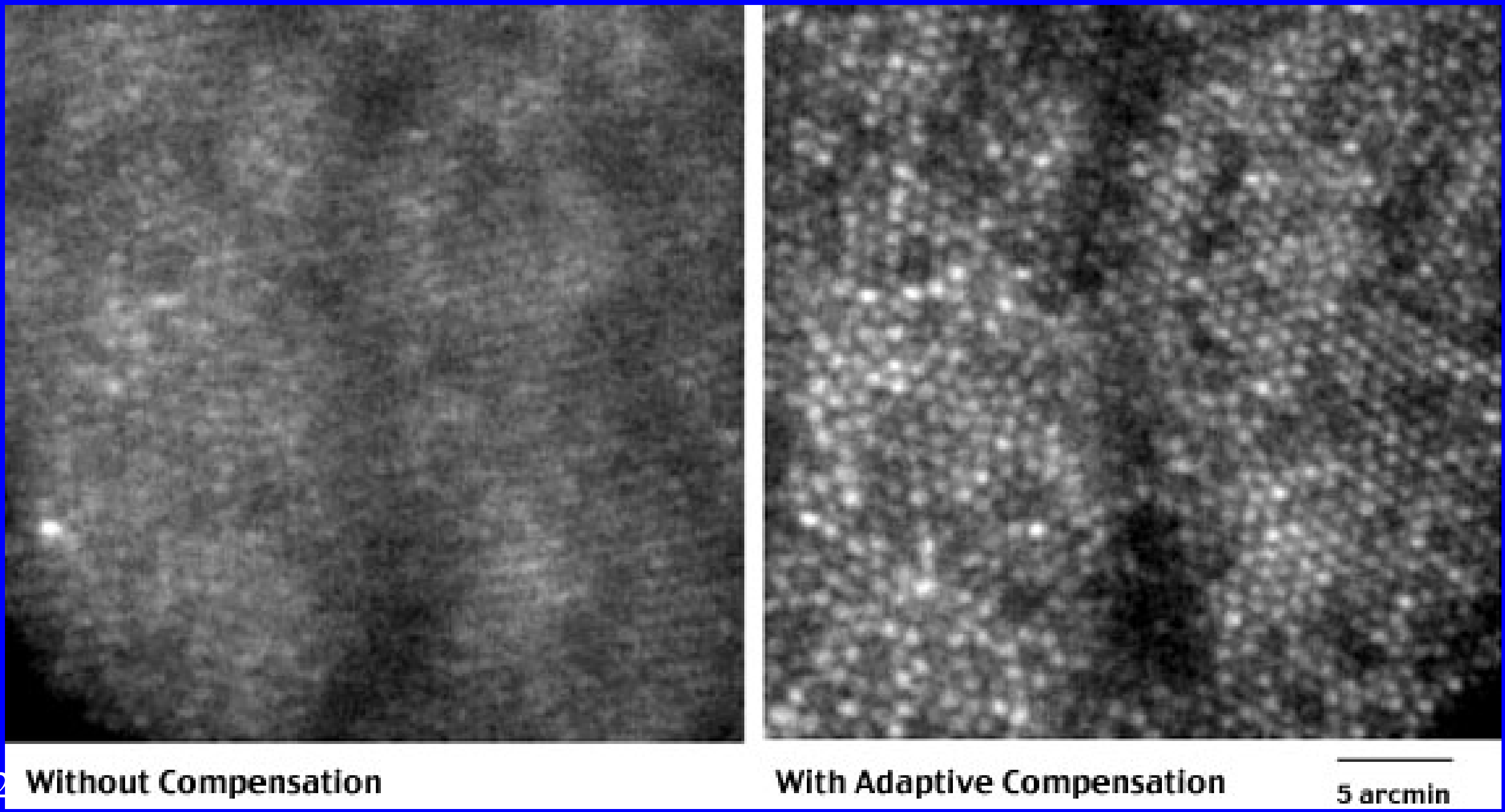
Example

Retinal image corrected for aberrations of anterior optics of the eye (Univ of Rochester)



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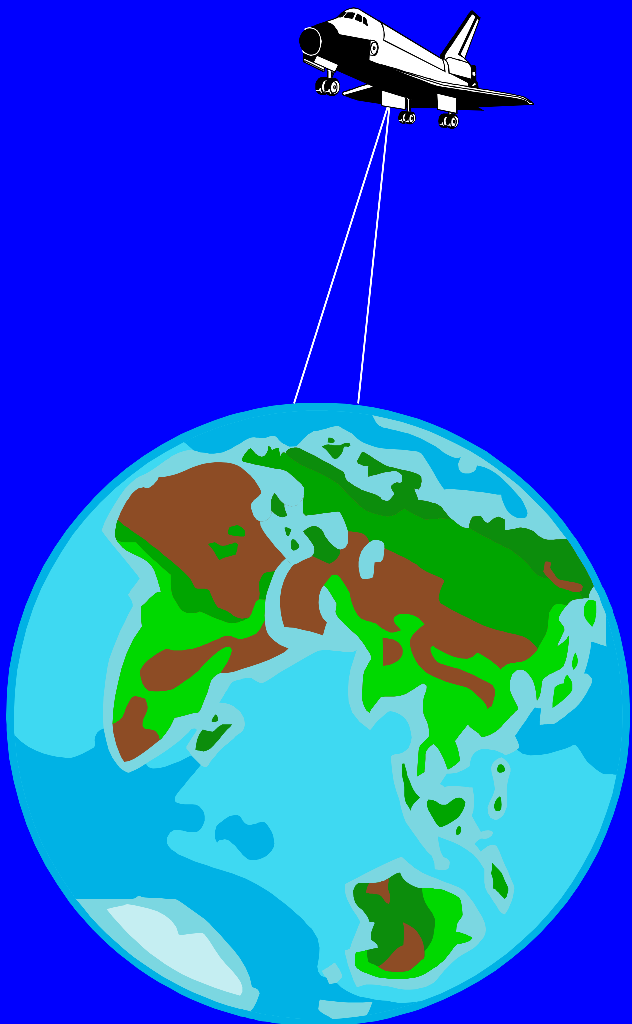
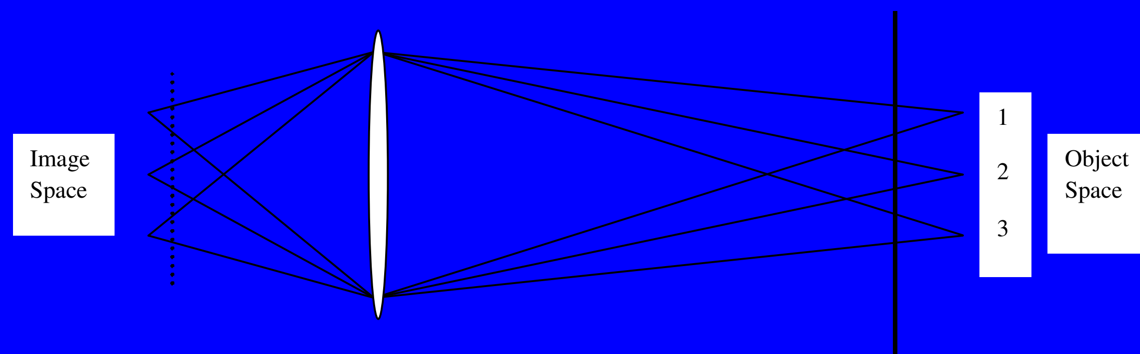
Adaptive Optics - in space?

- So if AO corrects terrestrial turbulence why use it in space?
  - Correction of atmosphere in imaging the ground from space?….

…Unlikely

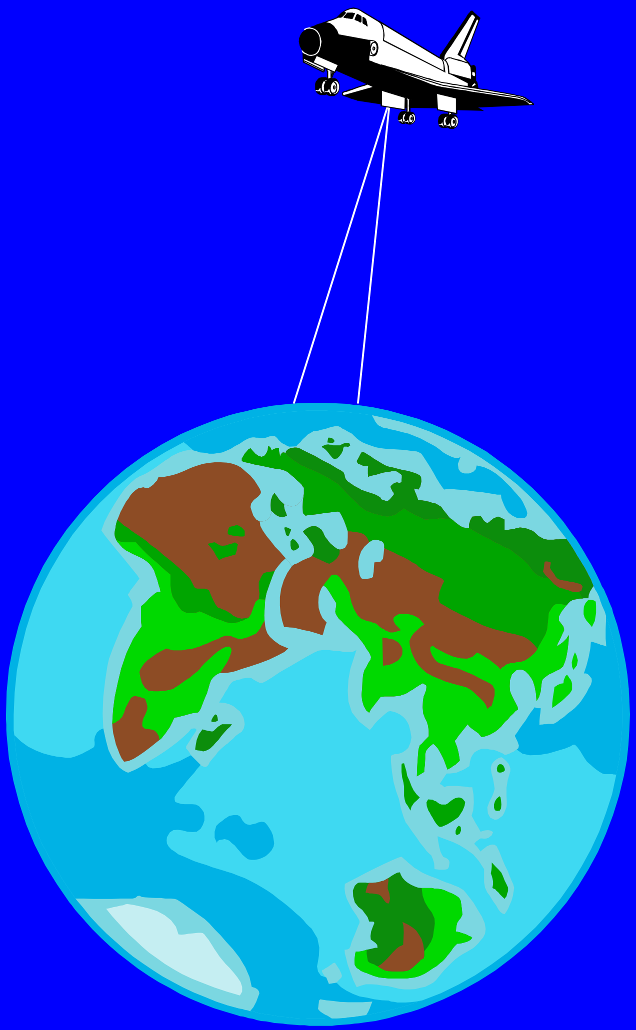


- Atmosphere is close to earth not observer
  - Isoplanatism problem



Turbulence-induced resolution limit $\lesssim$ 0.5m.

But…



- Lightweight, large optics in space could provide enhanced resolution from higher altitude
- Correction of thermal deformations during eclipse etc

Smart Optics - in space?

- Light-weighted optics?….

Light-weighting

- Use light-weighted optical components
    - Distortions in reduced-mass components can be corrected with AO
- Thermal compensation
    - Thermal distortions can be compensated using AO → reduced baffles and temperature control
- Active or adaptive optics

Light-weighting

- Thin mirrors can save a lot of weight
  - Modify/correct shape after deployment
  - Active structures
- Membrane mirrors, bimorph mirrors, liquid crystal lenses
  - Non-mechanical control of optical system peformance, optical switches, ...

Smart Optics - in space?

- Performance enhancement?...

Performance enhancement

- Instrumental flexibility
  - Non-mechanical focus in planetary cameras
  - Non-mechanical, lightweight zoom lenses
  - Optimisation of performance with ancilliary optics
- Active or adaptive optics

Smart Optics - in space?

- Optical signals?…..

Optical signals

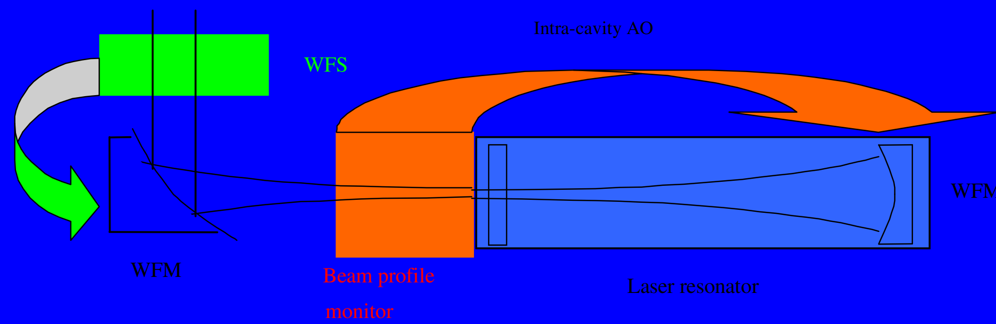
- Optical signals are
  - Fast, covert
  - Immune from EM interference
  - Fibre can be weight-efficient for signal transport
  - Available for inter-satellite comms in formation flying

Smart Optics - in space?

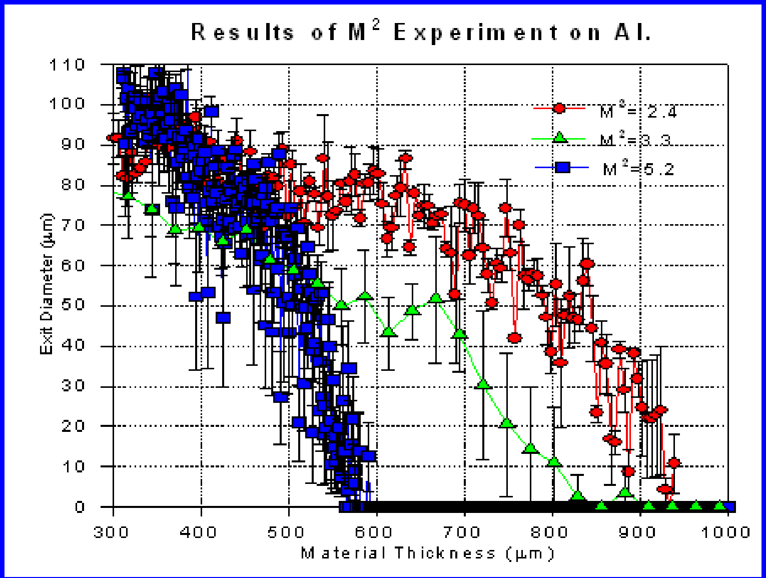
- One important feature that must be taken into account in thinking of AO or other ‘Smart Optics’ in space…
  - if the ‘Smart’ system fails it must do so in a way the leaves a useful instrument.

What about manufacture?

- Laser materials processing



- Control of laser beam
  - Depth of drilling
  - Quality of finish
  - Shape of holes
  - Quality of weld
  - ‘Designer’ fs pulses



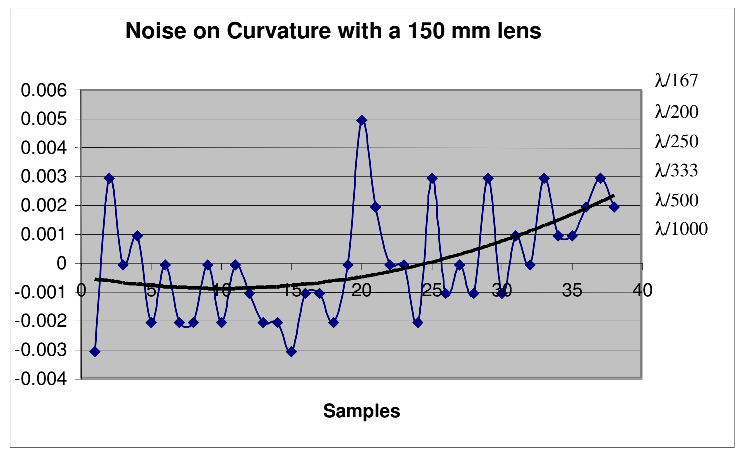
What about manufacture?

- Optical surfaces, optical systems
- Measurement of shape
  - Polished and rough surfaces
  - Quality of finish
  - optical system performance

Surfaces measured to 0.7nm rms

Heriot-Watt University
Edinburgh

Best Results



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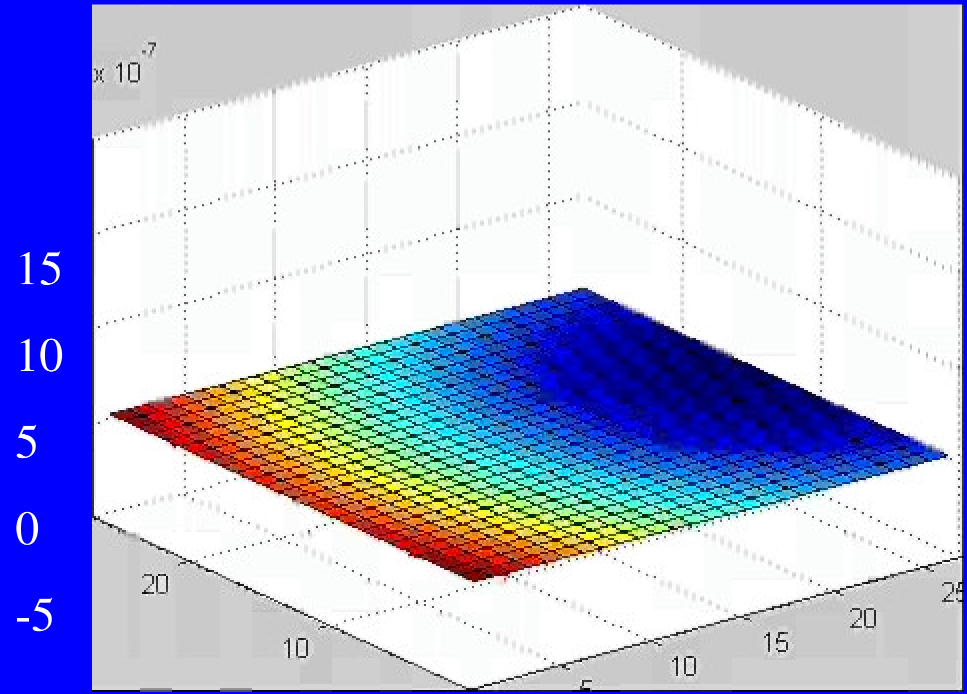
What about manufacture?

- Laminates
- Measurement of thickness and location
  - results to date
  - Location to ±20μm
  - on samples from 150μm to 8mm thick



Film thickness from 100nm to 10μm

Smart Optics - in space?

- Yes
  - Significant potential is easily identified
  - More is sure to come

OMAM - Optical Manipulation and Metrology

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OMAM

- Commercial goals:
  - Short-term ➢ Thin-film metrology
  - Medium-term ➢ 3-d surface metrology
  - Long-term ➢ BIL, surveillance

Leading to products with an established demand

OMAM

- A range of research goals of various nature
  - Incremental
    - improving wfs precision
    - relationship to national standard of length
  - Non-incremental
    - wfs on discontinuous and rough surfaces
    - optical μ-manipulation
    - fs lasers
  - PPARC interests
    - OWL/segmented/space optics
  - EPSRC interests
    - bio-medical and engineering

OMAM

- Project about to start
  - ➢Legal collaboration agreement signed
  - ➢3 research students in place
    - ➢Heather Campbell (PhD CASE student ATC)
    - ➢Clare Dillon (EndD student BAE SYSTEMS)
    - ➢David Faichnie (EngD student Scalar Technologies)
  - ➢RA applicants interviewed - offers being made

OMAM

- Work to date
  - Risk-reduction work on laminate structures (Scalar
    - $\pm$20µm interface location in structure 150µm to 8mm thick
    - $\pm 10^{-4}$ rad. on angle (parallelism) of interfaces
  - Generalisation of phase-diversity wfs
    - sufficient conditions established for generalised phase diverse functions (EOARD)