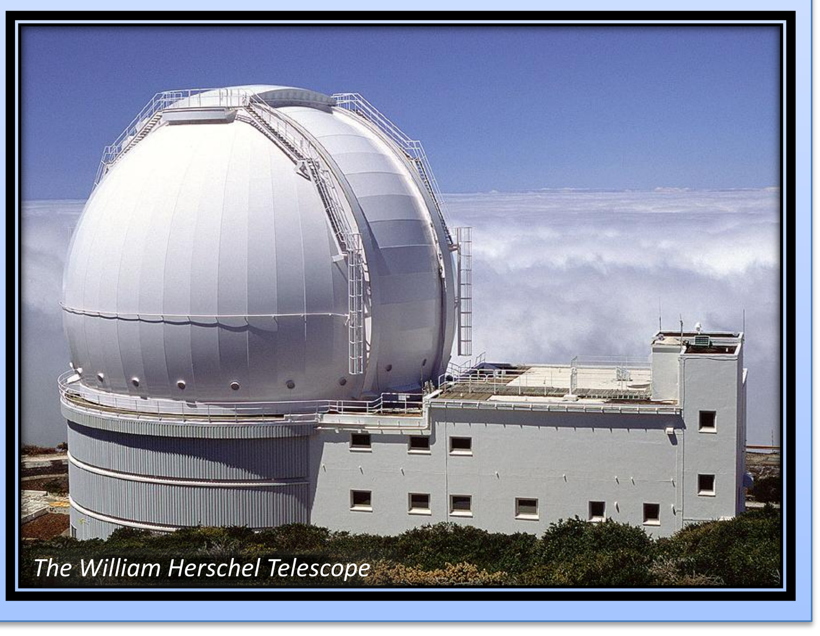
AOLI: Adaptive Optics Lucky Imager

Obtaining the highest resolution optical images in astronomy

Jonathan Crass[1,*], Bruno Femenía[2], Craig Mackay[1], Rafael Rebolo[2,3], David King[1]

Overview

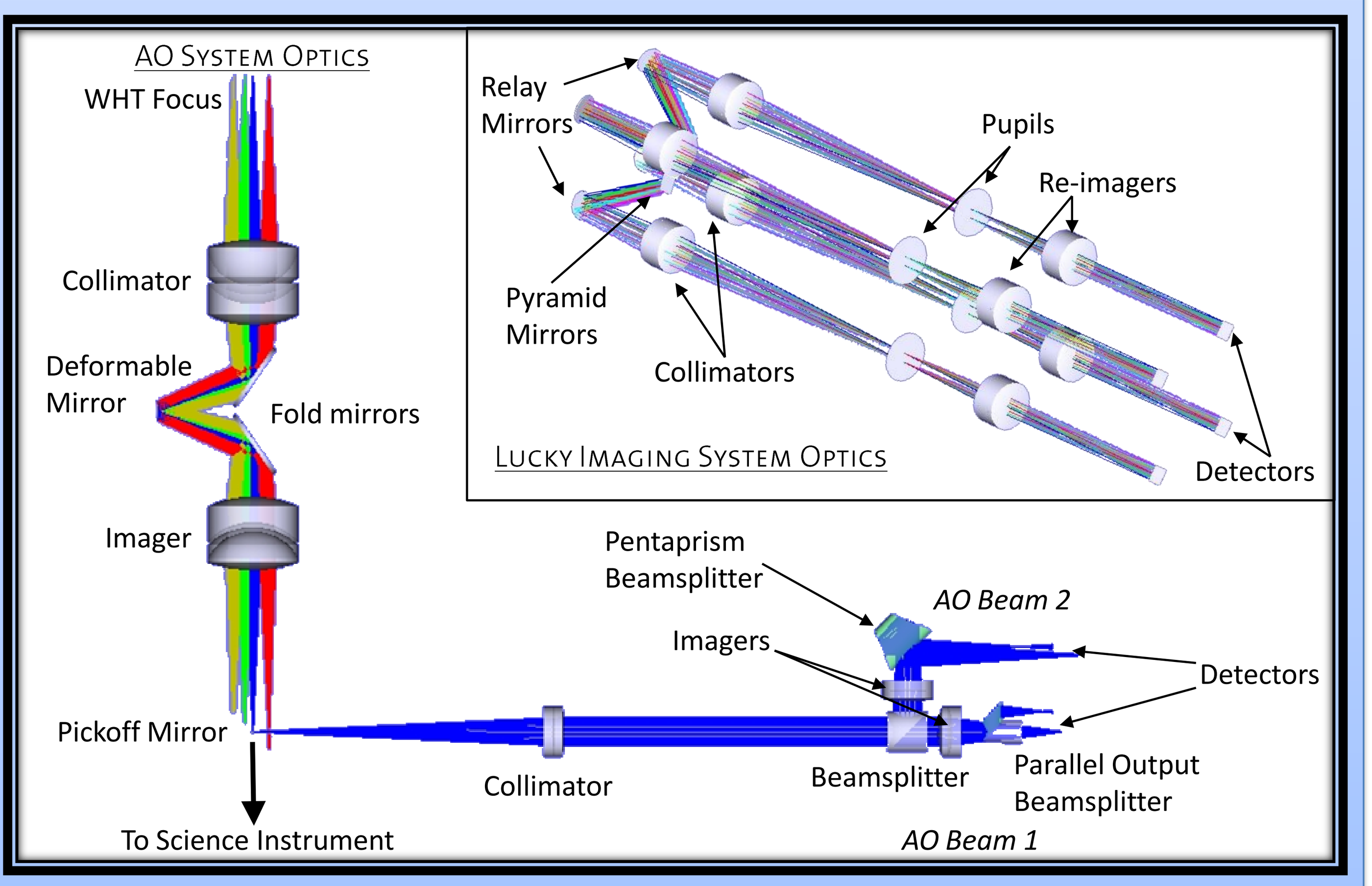
- The combination of adaptive optics and lucky imaging has been proven to deliver near diffraction limited images at visible wavelengths on five metre ground based telescopes. To date, this has been achieved through adaptive optics (AO) systems using Shack-Hartmann wavefront sensors based permanently on telescopes. In Racine (2006), it has been shown that this type of sensor is significantly less efficient than other detection methods.
- The Adaptive Optics Lucky Imager (AOLI) project combines low order AO and lucky imaging into a single instrument. The shortcomings of Shack-Hartmann sensors are addressed through the use of a dual-stroke curvature wavefront sensor as proposed by Guyon (2007). This technique offers vastly improved sensitivity allowing natural guide stars down to 19th magnitude to be used on the 10m class telescopes.
- The instrument will initially be used on the 4.2m William Herschel Telescope (WHT) before use on the 10.4m Gran Telescopio Canarias (GTC).



The William Herschel Telescope

Instrument Design

- AOLI comprises two separate components; a low order adaptive optics system and a lucky imaging science instrument.
- The AOLI science instrument is based on LuckyCam, an instrument developed at the Institute of Astronomy, University of Cambridge. This instrument has been successfully used on the 2.56m Nordic-Optical Telescope (NOT) on La Palma and the 200 Inch Hale Telescope at Mount Palomar.
- The science detector uses an array of four EMCCDs, each 1024×1024 px, to provide a contiguous imaging region of 2000x2000 px, with a field of view of 45×45" down to 12x12" and pixel scales of 22.5 to 6 mas.
- The AO curvature wavefront sensor contains two 1024x1024 px EMCCDs. Each CCD images two pupil planes through the use of parallel output beamsplitters with each beam imaging a different point along the ray path.
- The proposed deformable mirror for the AO system is the Alpao DM97. This is a continuous phase plate mirror with a total of 97 actuators giving 11 elements across the diameter each with a stroke (amplitude) of 60 microns. Simulations for this mirror show that it should be able to provide the required corrections on the WHT, however an increased number of elements will be required for the GTC.
- The AOLI science instrument will run at 30Hz, generating around 200MB of data per second. These images are selectively combined and aligned to produce an image approaching the diffraction limit.



The optical design of AOLI.

Scientific Justification

- AOLI will give a step increase in resolution over the Hubble Space Telescope (HST) of the same order gained by HST over conventional ground based telescopes. This increase will allow astronomers to investigate astronomical objects in unparalleled detail.
- The initial science case for AOLI includes investigation of:
  - Dynamics of low-mass binaries
  - Binary/multiple massive star systems
  - Globular Cluster cores
  - Micro-lensing systems
  - Star forming regions at high-redshift
  - Supernova studies in Local Group galaxies

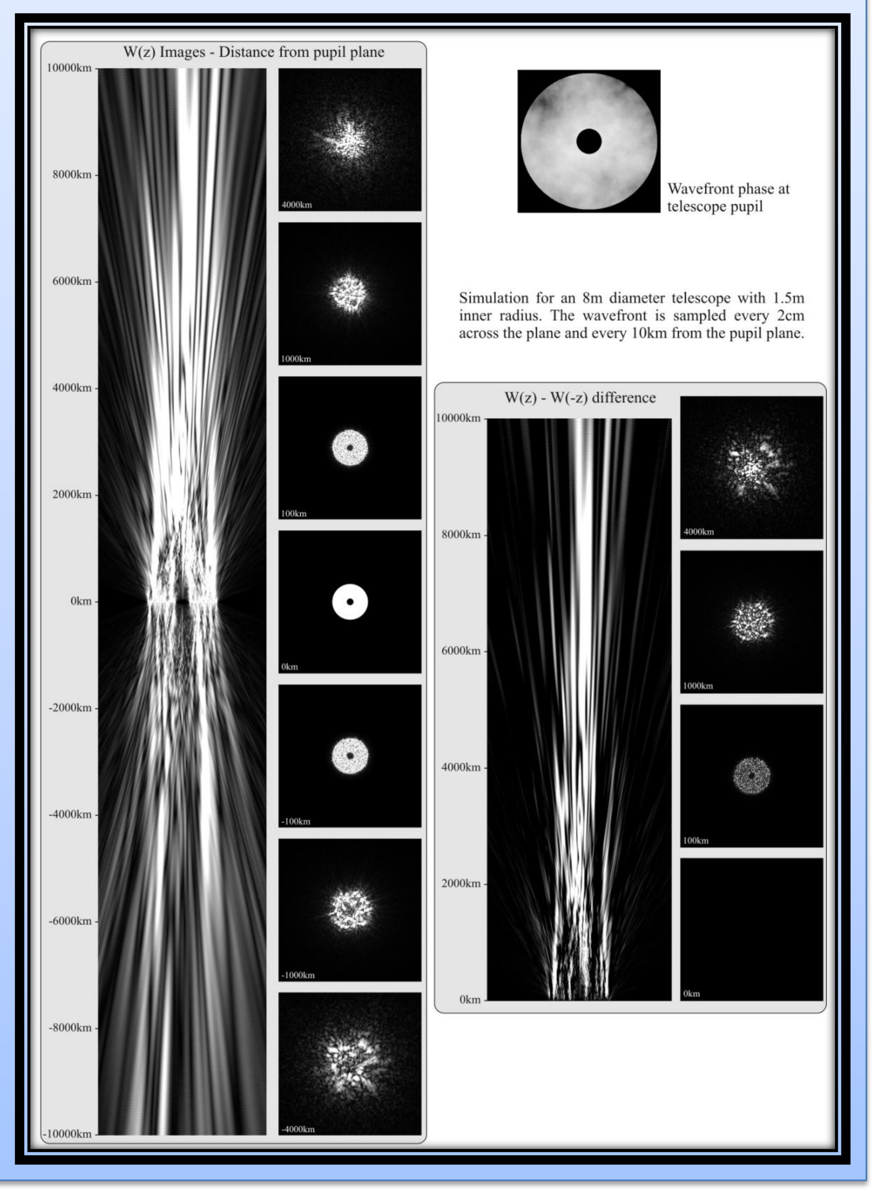
Gravitational Lensing in Abell 2218
Credit: Andrew Fruchter et al.

Curvature Wavefront Sensing

- The curvature wavefront sensor was first proposed by Roddier (1988). Curvature in the wavefront due to atmospheric distortions causes patches to change their brightness as wavefronts converge or diverge through the plane.
- The idea of curvature sensing is relatively simple (*i.e.* taking images at different distances from the pupil plane) and the method offers key advantages over Shack-Hartmann sensors (Guyon, 2005).
- Instead of the four or more pixels required for each subaperture in a Shack-Hartmann sensor, in a curvature sensor one pixel is used giving an increased number of photons per pixel. This makes it sensitive to much fainter natural guide stars (down to 19th magnitude) and provides significant sky coverage without the need for laser guide stars.

Simulating Data

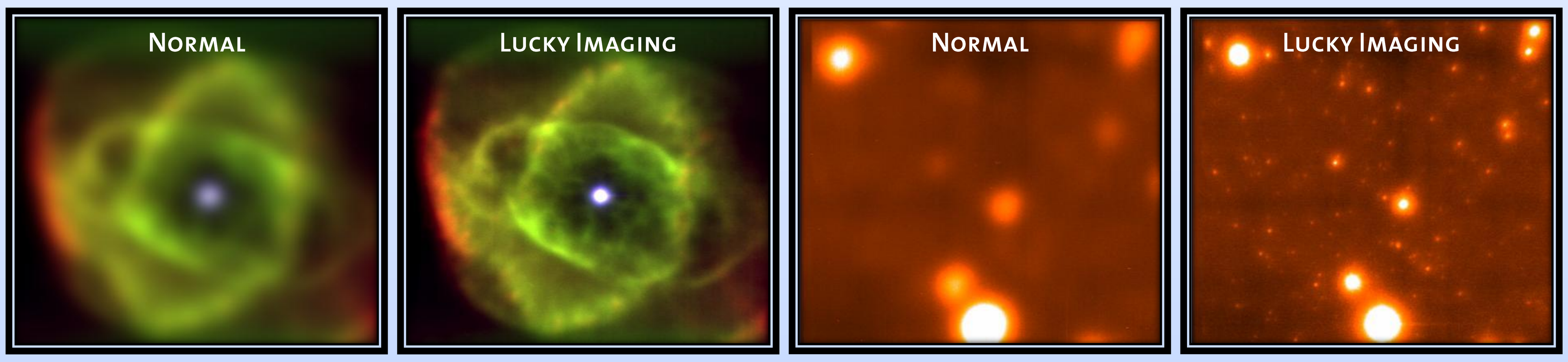
- There are several packages available to model the propagation of light through turbulent atmospheres and telescope systems. Arroyo was chosen due to its base in C++, allowing development of systems at a low level, providing flexibility when modelling.
- To date, Arroyo has been used to verify previously published work using other simulations. This has been successful with consistent results being generated.
- The next stage of the project is to generate simulated intensity patterns at the required distances from the pupil plane.



Simulated intensity of a turbulent wavefront as a function of distance from the telescope aperture.

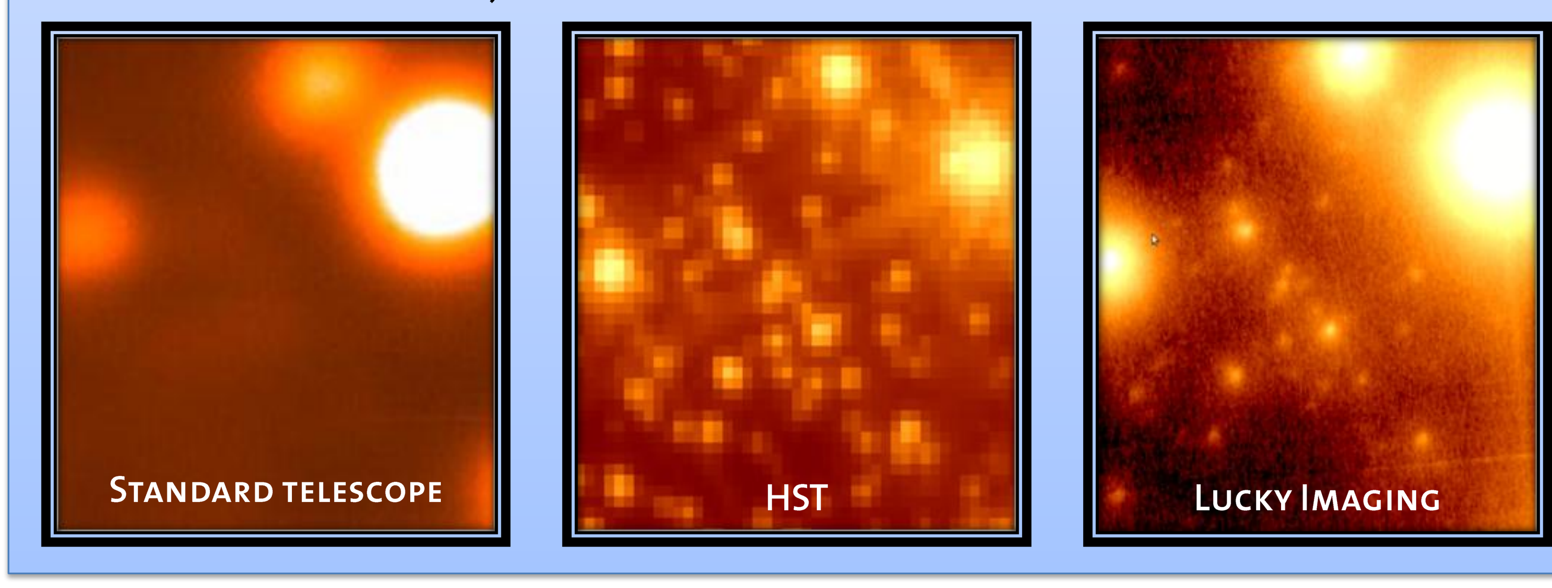
Validation of the Technique

LuckyCam on the 200 Inch Hale Telescope, Mount Palomar, CA, USA – July 2007



A single exposure on the Hale Telescope (left) compared with Lucky Imaging on the same instrument (right). The two left hand images show the Cats Eye Nebula while the right show a field in globular cluster M13.

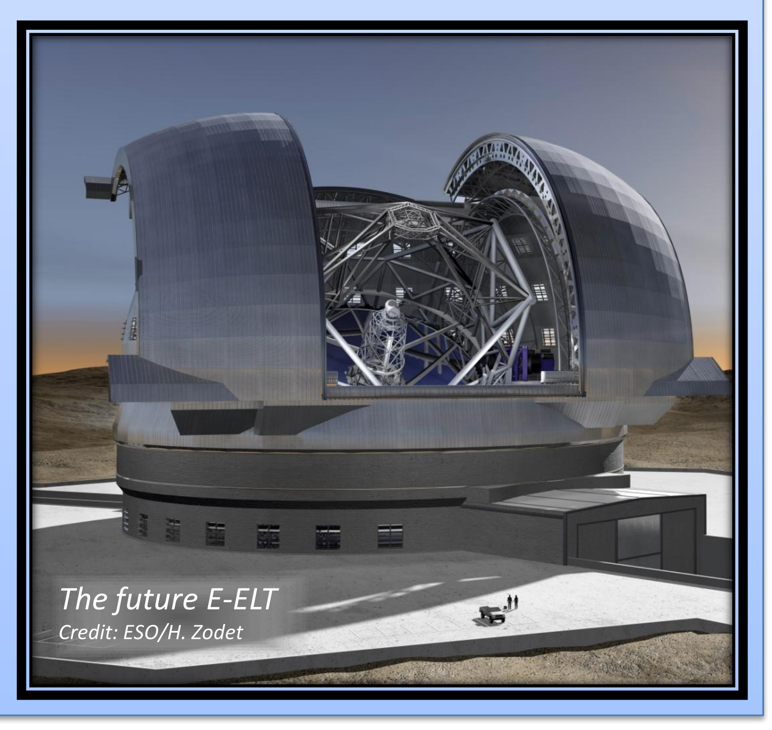
Standard Telescopes, the Hubble Space Telescope and Lucky Imaging



The same field of M13 using a standard telescope, HST and Lucky Imaging.

Summary

- The AOLI project combines the techniques of adaptive optics and lucky imaging to produce the highest resolution optical images ever taken in astronomy. This technique has been proven though observations on the 200 Inch Hale Telescope and the Nordic Optical Telescope.
- The AOLI AO System uses a curvature wavefront sensor to allow faint natural guide stars to be used. This allows significantly improved sky coverage using natural guide stars and facilitates near diffraction limited imaging.
- AOLI will be demonstrated on the William Herschel Telescope before being moved to the Gran Telescopio Canarias (GTC).
- For the next generation of ground based telescopes, questions remain about the capabilities of AO to provide the level of correction required for diffraction limited imaging at optical wavelengths. AOLI may offer a solution with feasible scalability to larger telescopes.



The future E-ELT
Credit: ESO/H. Zodet

The AOLI project is a collaboration between research institutions across Europe, including:
- Institute of Astronomy, University of Cambridge, UK[1]
- Instituto de Astrofísica de Canarias, Tenerife, Spain[2]
- Isaac Newton Group of Telescopes, La Palma, Spain
- Technical University of Cartagena (UPCT), Spain[3]
- University of Cologne, Germany

[*] jcrass@ast.cam.ac.uk

University of Cambridge

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