Astronomical Reflections on Richard Gregory

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The Right Kind of DNA!

- Richard Gregory came from a long line of extraordinary creative and able scientists.
- James Gregory FRS (1638 –1675), was a Scottish mathematician and astronomer.
- First described the parabolic reflecting telescope – the Gregorian telescope, long before Newton.
- Also discovered infinite series representations for several trigonometric functions.
Richard Gregory’s Interest in Astronomy

- Richard Gregory’s father was the director of the Mill Hill Observatory in North London.
- From an early age, Richard was aware of the challenges of atmospheric turbulence for astronomy.
- Isaac Newton thought it was hopeless.
- Richard developed a very novel approach to minimising the blurring of images obtained on ground-based telescopes.

- Human vision derives a great deal of information from the changes in a scene, and the differences perceived by each eye.
- Richard developed a hardware method of differencing two astronomical photographs.
Richard Gregory’s Interest in Astronomy

• When the two images are perfectly aligned (one positive and one negative) the overall light transmission is minimised.

• If a new image is much sharper than the old one then the sharp core is detectable while the diffuse halo is rejected.

• This leads to significant image sharpening.

• Richard was funded by The Royal Society Paul Instrument Fund to build a demonstration instrument on a telescope in Cambridge.

• Worked with David Dewhurst (also of Corpus Christi College) and the Cambridge Thorrowgood telescope (1864).

• Built by Stephen Salter in 1966.
Richard Gregory’s Seeing Improver

- This instrument allowed exposures to be created out of only those moments when the image was perfectly aligned with the master image (g).
- It used to photomultiplier (j) as an alignment sensor (minimum light).
- This triggered shutter (d) to open and integrate the light in a camera (e).
Richard Gregory’s Seeing Improver

• In the laboratory the results were impressive.
• Unfortunately, telescopes of the day were too unstable to maintain alignment.
• Richard then designed an automated tracking corrector.
• The mechanical stability of telescopes continued to be a limiting constraint.
• But the technique was entirely valid and variations are in use today.
• We call it Lucky Imaging.
High Angular Resolution From Lucky Imaging

- Photon-counting CCDs are the key technology.
- Fast (10-30Hz) imaging freezes the motion due to atmospheric turbulence.
- Sharpest images are shifted and added.
- Routinely gives Hubble resolution images on Hubble size telescopes with 10-30% selection.
- User may subsequently trade off resolution against sensitivity.

0.12 arcsec binary, $\Delta_{\text{mag}} \sim 2.5$ imaged with LuckyCam on the NOT 2.5m telescope (June 2005)
The Einstein Cross

- The image on the left is from the Hubble Space Telescope Advanced Camera for Surveys (ACS) while the image on the right is the lucky image taken on the NOT in July 2009 through significant amounts of dust.

- The central slightly fuzzy object is the core of the nearby Zwicky galaxy, ZW 2237+030 that gives four gravitationally lensed images of a distant quasar at redshift of 1.7
More Resolution From Lucky Imaging

- Lucky Imaging gives Hubble resolution images in the visible routinely on 2.5 meter class telescopes.
- Field of View (critical for ground-based astrometry) is typically \( \sim 1 \) arcminute across.
- Image processing extends this to \( >2 \) arcmin.

- Hubble resolution (120 milliarcsec) very nice, but large (>2.5m) telescopes should be able to do much better.
- A 4.2m (10.5m) telescope should give a near-IR resolution of 40 (15) milliarcsec, and 24 (10) milliarcsec in visible (green) ……………………in theory!
Lucky Imaging on Much Larger (>2.5m) Ground-Based Telescopes

- On larger telescopes, the chance of getting a sharp image becomes vanishingly small.
- Most of the turbulent power is in the largest scales.
- These may be removed with low order adaptive optic systems.
- Technique tried on the Palomar 5 m (200 inch) telescope behind their low order PALMAO system.

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Large Telescope Lucky Imaging.

- Globular cluster M13 on the Palomar 5m.
- Natural seeing ~650 mas.
- Imaged via the PALMAO system and our EMCCD Lucky Camera.
- Achieve ~40 mas resolution.
- This is the highest resolution image ever taken in the visible.
- Field shown here is about 7x7 arcsec.
• The comparison of our system with Hubble Advanced Camera (ACS) is quite dramatic.

• Lucky/AO image resolution ~ 40 milliarcseconds or ~3 times Hubble.
AOLI: Adaptive Optics Lucky Imager

- We are presently building an instrument using these principles for use on 2 telescopes on La Palma (Canary Islands).
- The angular resolution is predicted to be 4-8 times Hubble.
- It should be completed in about 2-3 years from now.
- It will give another 8x step in resolution similar to that originally provided by Hubble all those years ago.
- Richard Gregory’s intellectual DNA is all over it!