L3CCD'S: LOW READOUT NOISE CCD'S IN ASTRONOMY

Lucky Exposures Technique

Alastair Basden, BobTubbs, Craig Mackay
Institute of Astronomy, Maddingley Road, Cambridge, UK

Abstract: Perturbations in the earth's atmosphere mean that we do not get diffraction-limited images on anything but the smallest telescopes, even if they have perfect mirrors. However, changes in the atmosphere occur on timescales of order 10ms. Images taken with exposures shorter than this will freeze the atmosphere in the image, and occasionally, a flat wave front will be imaged. Shifting and adding many such images will result in a diffraction limited picture of the sky. We report on some results obtained using a low light level charge coupled device (L3CCD), on the Nordic Optical Telescope (2.5m) in the I band. The full width half maximum of a point object is about 0.1 arcsec, better than that given by the Hubble Space Telescope.

Key words: L3CCD, Lucky exposure, Adaptive optics, Diffraction limited.

1. INTRODUCTION

In the quest for imaging of fainter objects, telescopes have grown in size. Atmospheric fluctuations mean that images produced are no longer diffraction limited, but smeared. Adaptive Optics (AO) has sought to overcome these problems by adjusting mirror surfaces in real time to correct the atmospheric effect. This however, is not straight forward in the infrared, and more difficult in the optical. The isoplanatic patch is small (~10 arcseconds).

Changes in the atmosphere occur on timescales of order 10ms. By imaging the sky with an exposure time less than this, it is possible to freeze the atmosphere, so that little smearing occurs in the image. If this is done many times, eventually a flat wave front will be imaged, giving a diffraction limited image of the sky. Shifting and adding many such images allows us to build up a picture of the sky.

The fast frame rate means that each image may be very faint. However, reading a CCD fast usually results in a noisy signal, limiting the magnitude to which objects can be observed. A fast CCD with very low noise readout is required, characteristics which are matched by low light level CCD's (L3CCD's). Tests with these chips have been successful, the elimination of read noise allowing us to reach up to ten magnitudes fainter.

2. L3CCD CHIP

An L3CCD is able to provide a large internal gain by passing electrons through the multiplication register, an extension of the serial register. As electrons pass through this register, a high voltage on one of the pins can cause avalanche multiplication to occur. The probability of creating an extra electron at each stage is small (1-2%), but many such stages can lead to a large overall gain, which can be adjusted between 1-10000. The output signal can then much greater than the readout noise, resulting in a high signal-to-noise ratio for a single electron detected by the imaging array. Several modes are available for reading out the CCD, depending on light level, as discussed by Basden (these proceedings). Here, we use an analogue mode, treating the output exactly as we would a conventional CCD. This leads to increased statistical noise due to the multiplication process.

3. RESULTS

The isoplanatic patch is about 60 arcsec in the I band when using Lucky Imaging, greater than that achievable with AO. This is limited by telescope mirror imperfections. Fainter stars are affected by photon shot noise, though shifting and adding many such images removes this problem. A thinned L3CCD is able to use reference stars as faint as 17^{th} magnitude. A sample of results is shown in figure 1.

3.1 Observing efficiency and quality

When using this imaging technique, we throw away a large fraction of images, resulting in poor observation efficiency. Observing efficiency can be improved at the expense of resolution, by using a larger fraction of images. This gives poorer results, though is still dramatically better than a long-exposure image, the quality degrading only slowly. The fraction of images used is determined by the required sensitivity and resolution, typically between 1-10%.

Image quality is found to be affected by the magnitude of the reference star, and by angular separation between the reference and science objects.

Using 1% selection over one hour of observation on a 2.5m telescope, the magnitude limit is I~23 with a thinned CCD with diffraction limited imaging (0.1-0.13 arcsec resolution), assuming seeing of about 0.5 arcsec. This can be increased to I~25 by selecting the best 10% of images, though the resolution is poorer (0.12-0.15 arcsec).

Results could be improved further by using a multiple threshold readout

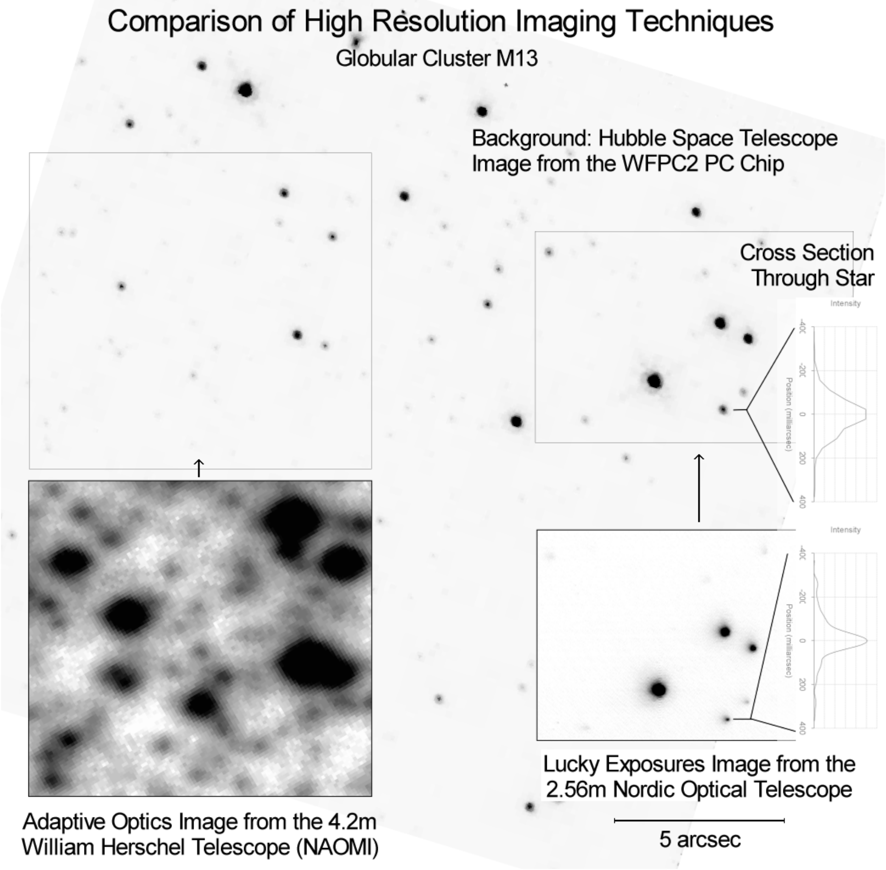

Figure 1: Comparison of imaging techniques. Background is from Hubble Space Telescope (HST), overlain with images from adaptive optics (AO) and lucky exposure (LE) techniques. The full width half maximum from each technique is: HST 0.12-0.15 arcsec, AO 0.4 arcsec, LE 0.1 arcsec. Lucky exposure image was obtained using three seconds of data from a 300 second observing run.

mode (Basden, these proceedings), as this would increase the signal to noise levels in the faintest parts of the image, allowing greater detail.

4. HARDWARE REQUIREMENTS

There is need to develop high speed controllers for L3CCD's, which are capable of pixel rates up to 15-25MHz, with multiple output channels and parallel signal chains. There is also a need for operation in several readout modes, current controllers only supporting analogue readout. Integrated hardware needs to be developed to sort, assess and process image data in real time. This is made possible by the current generation of digital signal processors, for example, Analog Devices SHARC-21160 chip, which we will use.

5. CONCLUSIONS

The Lucky imaging technique provides, at low cost, essentially the only way to achieve ground-based diffraction limited imaging in the visible. Virtually 100% of the sky is accessible, and the isoplanatic patch is greater than with adaptive optics.

Larger telescopes can be used, dividing them up into a set of sub-apertures. The summation of independent sets will then improve the limiting magnitude.

REFERENCES

1. Diffraction-Limited CCD Imaging with Faint Reference Stars.
   Tubbs, R. N.;Baldwin, J. E.; Mackay, C. D.; Cox, G. C. A&A 387 L21, 2002.

2. Diffraction-limited 800 nm imaging with the 2.56 m Nordic Optical Telescope.
   Baldwin, J. E.; Tubbs, R. N.; Cox, G. C.; Mackay, C. D.; Wilson, R. W.; Andersen, M. I.
   A&A 368 L1, 2001.