

Correlation wave-front sensing at Lick

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Many challenges lie ahead in LGS WFS

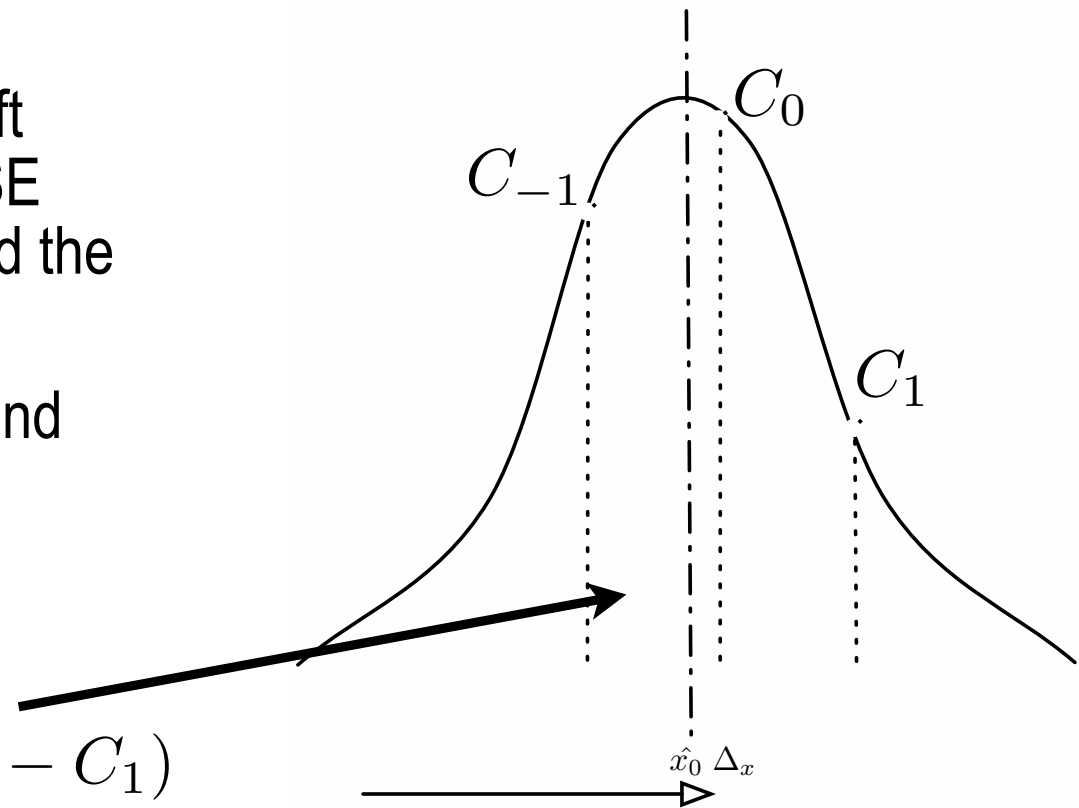
- § WFS may be operated in open-loop, requiring algorithms which have a linear response with spot displacement.
- § Structure in sodium layer may lead to non-uniform spots.
- § Spot size changes and truncation will lead to WFS gain changes, and incorrect operation when references are used.
- § WFS may require more than 2x2 pixels, which leads to increased noise propagation, especially due to read noise.

- § All of these problems have the potential to be solved using Correlation as the WFS algorithm.
- § We will in particular address spot size and noise with Lick data.

Correlation finds the shift optimally

- § Correlation finds the shift which minimizes the MSE between a reference and the image of interest
- § Use parabolic fitting to find sub-pixel shift estimate

$$\hat{x}_0 = \Delta_x + \frac{0.5(C_{-1} - C_1)}{C_{-1} + C_1 - 2C_0}$$



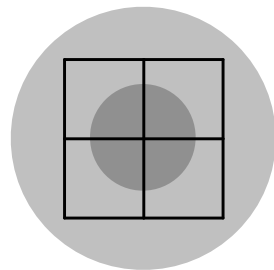
Peak of sampled correlation function

Detailed performance analysis possible

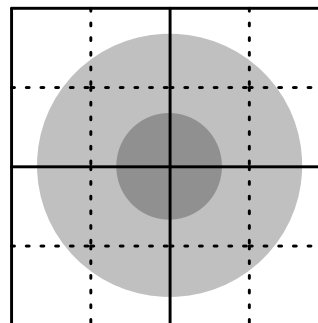
- § Using a linearization of the interpolation formula, the bias, gain and error variance of Correlation for an arbitrary image can be calculated.
- § The more spatial frequency content in an image, the less error in the shift estimate.
 - § *Points are very good scenes*
- § For photon noise, Correlation follows the same inverse-power law between RMS error and SNR.
- § For read noise, Correlation has substantially lower noise propagation than Centroiding.
 - § *For 2x2 versus 4x4, Correlation has nearly the same photon and read noise propagation as Quadcell and is lower than 4x4 Centroiding*

Lick WFS setup allows 4x4 pixels

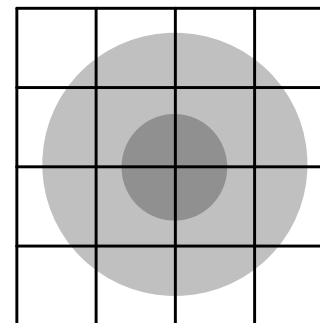
- § Lick AO has 4x4 pixels plus 2-pixel guard bands
- § Default WFS algorithms are Quadcell on 2x2 and Binned Quadcell on binned 4x4
- § Dave Palmer added 4x4 Correlation to code
- § Two methods to get slopes **through time**:
 - § *Closed-loop control with full telemetry for any WFS algorithm*
 - § *Open-loop observation with x-slopes for 2 methods output as telemetry*



Quadcell

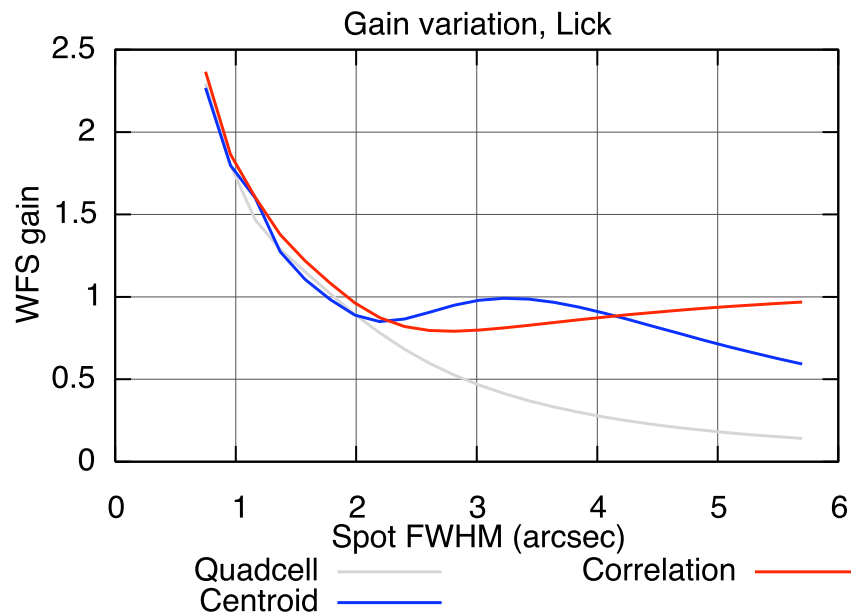


Binned



Correlation

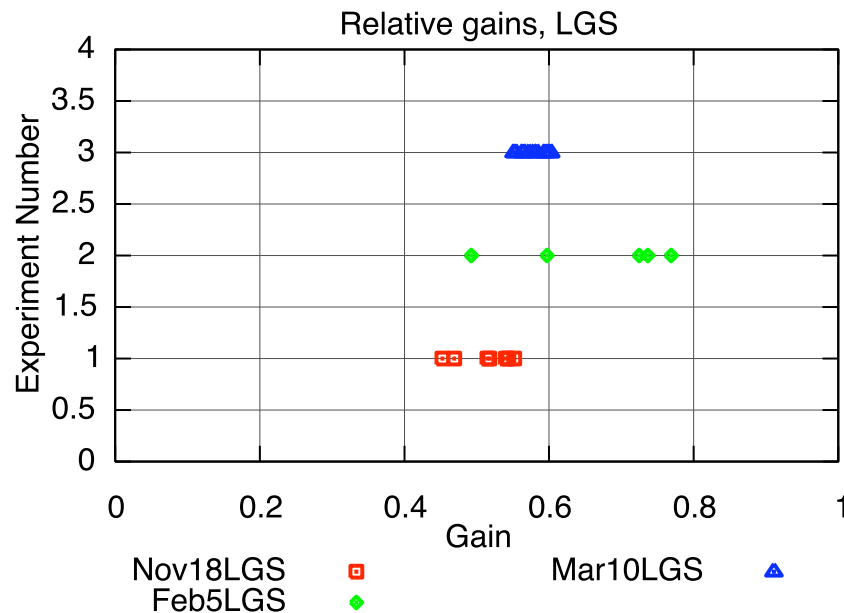
Correlation is less sensitive to lost light



WFS is Nyquist sampled at
spot FWHM of 3.36 arcsec

- § Simulation results for Lick WFS configuration
- § If spot size is too small, all algorithms are same
- § As spot size increases, Quadcell then 4x4 Centroid have lower gain due to truncation
- § Correlation less sensitive to spot size changes

Gain varies significantly for LGS case



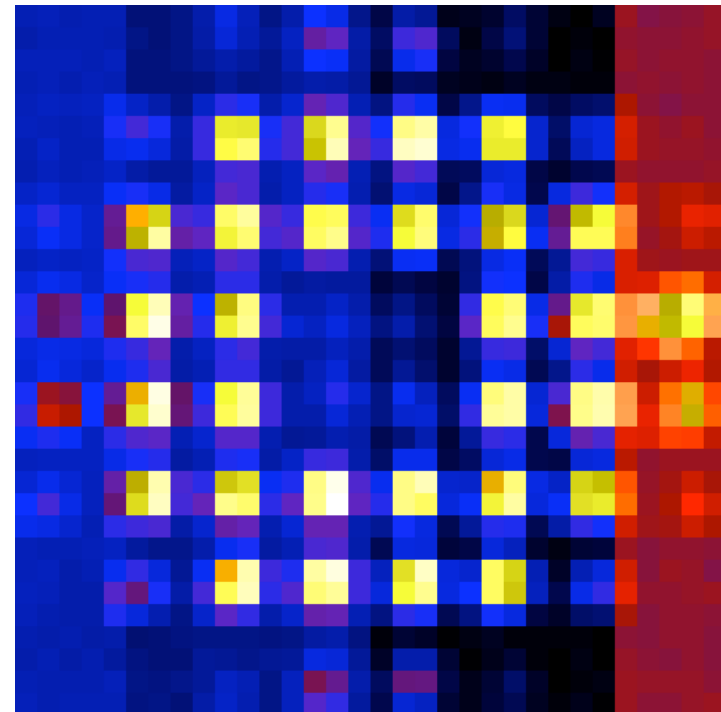
§ Gain determined in comparison to Correlation gain on several different nights in dual-observation mode

§ Using NGS and probes, Correlation and Quadcell have same gain

Gains determined by comparing power spectra of observations of same open-loop aberration

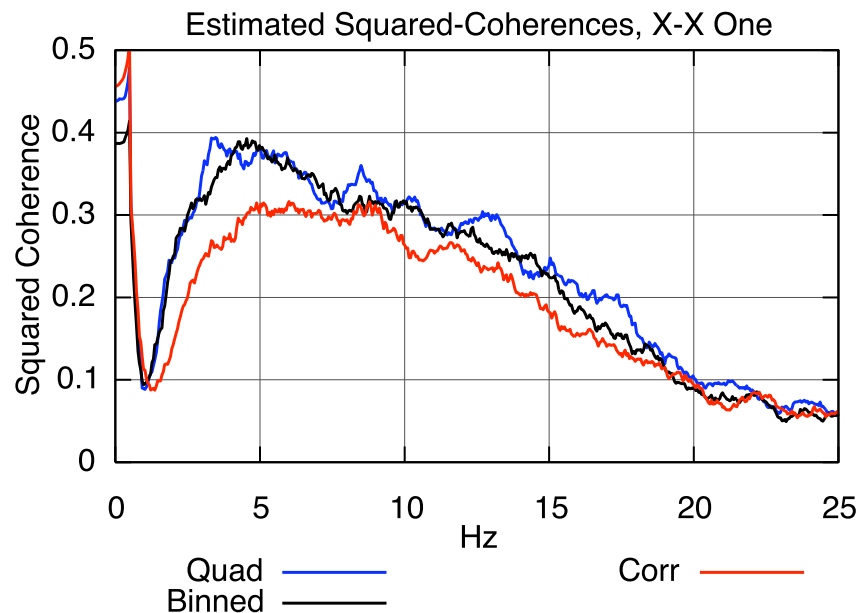
Spot size is substantial with LGS

- § Lick pixel size is 1.9 arcsec
- § In LGS case, spots are significant in size - this means that signal is present outside the inner 2x2 pixel region for the Quadcell
- § Based on gain estimations and simulation (see last slides), LGS spot size is as big as 3.5 arcsec



Average of 100 frames of WFS CCD.
Guard bands removed; no flat fielding.
Feb 5, 2004 LGS

Correlation makes slopes less coherent



Data from Feb 5, 2004
5 interleaved closed-loop
measurements for each method.
No references used for Corr. Refs
used for Quad and Binned.

- § For neighboring subapertures, evaluate temporal coherence of slopes in closed loop
- § The better the AO correction, the less coherent the slopes will be
- § Open-loop coherences in this temporal band are over 0.6

Future plans and directions

§ We would like to do another test at Lick:

§ *Get references for each method.*

§ *Take science images.*

§ LGS research directions:

§ *Find the best reference dynamically.*

§ *Evaluate the best pixel size, algorithm given CCD and LGS characteristics.*