Slope estimation and wavefront reconstruction for laser tomography adaptive optics at the Giant Magellan Telescope

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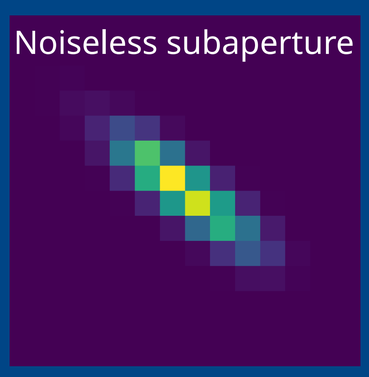
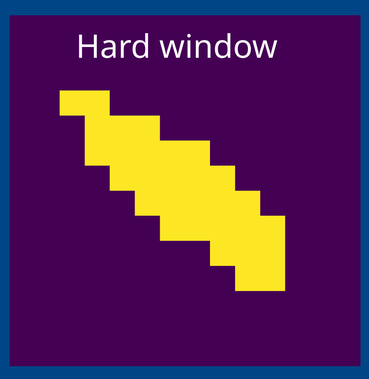
Efficient centroiders and a non-diagonal noise covariance matrix mitigate LGS elongation on ELTs

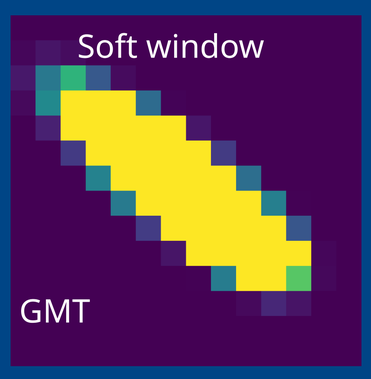
Weighted centroid



The pixel values are multiplied by pixel weights before computing the centroid.

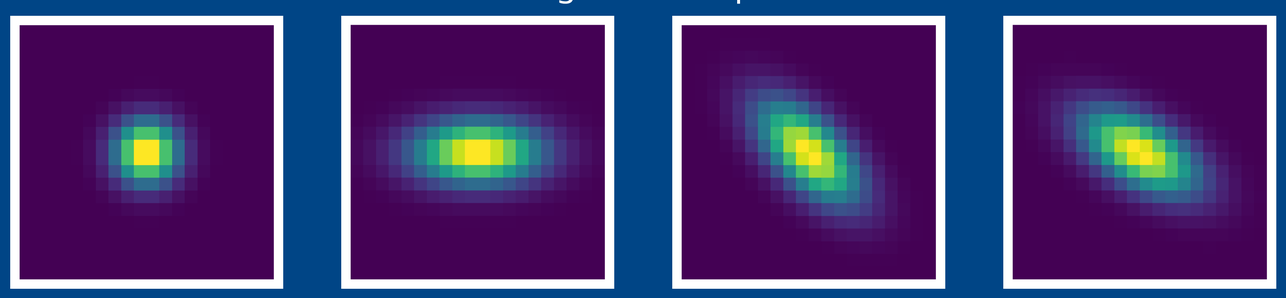
The pixel weights are configurable and vary from subaperture to subaperture.



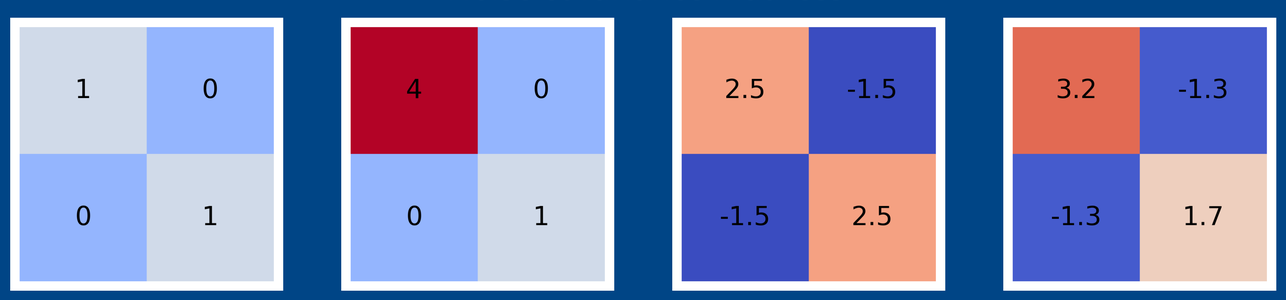


Non-diagonal noise covariance matrices

Elongated LGS spots

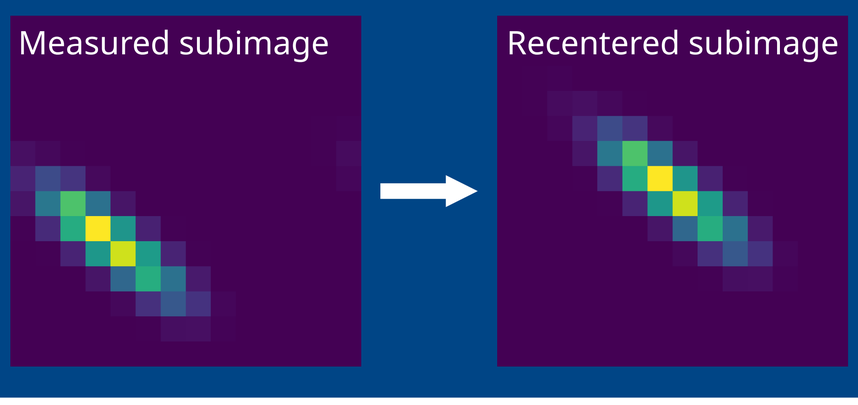


Noise covariance matrices



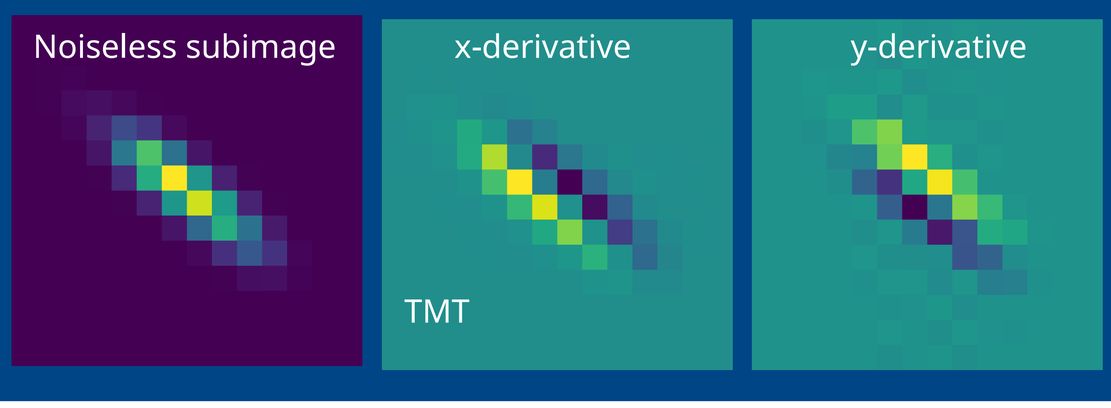
Dynamic recentering

Compute weighted centroid
Recenter subimage
Recompute weighted centroid and add to first weighted centroid



Matched filtering

Compute the x- and y-derivative of the noiseless subaperture
Multiply by the measured pixel values to obtain x- and y-centroids



Conclusion

To obtain optimal performance using LGSs on an ELT:
- Use the weighted centroid algorithm with soft weights
- Dynamic recentering helps a lot for any centroid algorithm
- Use a measured non-diagonal covariance matrix

Simulation results

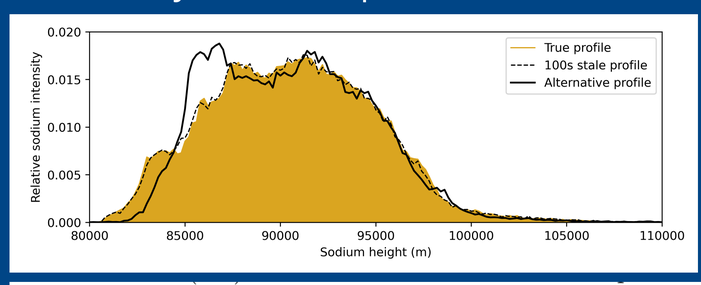
Sensitivity to noise

Algorithm	No noise	With noise
Centroid	180.0	249.8
Weighted centroid, hard window	186.7	200.1
Weighted centroid, soft window	180.2	196.9
Weighted centroid, HARMONI weights	212.3	224.0
Weighted centroid, hard window, dynamic recenter	182.2	197.2
Weighted centroid, soft window, dynamic recenter	178.7	193.8
Matched filter	178.8	200.0

Sensitivity to jitter (uplink tip-tilt errors)

Algorithm	0″	0.05″	0.1″	0.15″	0.2″
Weighted centroid, hard window	200.1	200.6	205.7	213.1	222.4
Weighted centroid, soft window	196.9	198.0	200.8	205.5	211.2
Weighted centroid, HARMONI weights	224.0	228.5	239.0	256.2	276.5
Weighted centroid, hard window, dynamic recenter	197.2	197.0	197.1	197.5	197.8
Weighted centroid, soft window, dynamic recenter	193.8	193.9	195.6	195.4	195.3
Matched filter	200.0	200.9	203.2	206.8	211.5

Sensitivity to sodium profile



Algorithm	Correct	100 s stale	Incorrect
Weighted centroid, hard window	213.1	213.0	212.4
Weighted centroid, soft window	205.5	205.4	206.5
Weighted centroid, HARMONI weights	256.4	251.0	238.3
Weighted centroid, hard window, dynamic recenter	197.5	196.9	198.4
Weighted centroid, soft window, dynamic recenter	195.4	196.8	197.2
Matched filter	206.8	207.2	231.3

Noise covariance matrix: uniform, diagonal and non-diagonal

	Uniform	Diagonal	Non-diagonal
No noise, no jitter	180.2	178.6	177.6
With noise, no jitter	196.9	187.2	184.3
With noise, with 0.15″ jitter	205.5	196.7	195.3