



LIFT@Keck: Analysis of performance and first experimental results

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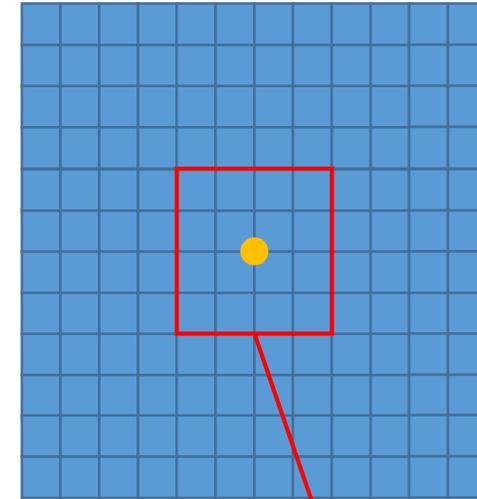
[D. Mawet's talk monday]

- Upgrade of Keck II AO system (KPIC) → need for a low-order (NGS) sensor in LGS mode
- Near-infrared tip/tilt sensor on Keck I (TRICK) proven efficient → interest for a NIR focal plane sensor
- LIFT: low-order focal-plane sensor developed at Onera

→ Occasion for a fully operational demonstration for LIFT
→ Optimized low-order sensing for Keck

- 2 tracks:
 - LIFT as new sensor for Keck II (new design)
 - LIFT as an upgrade of TRICK for Keck I (same design)

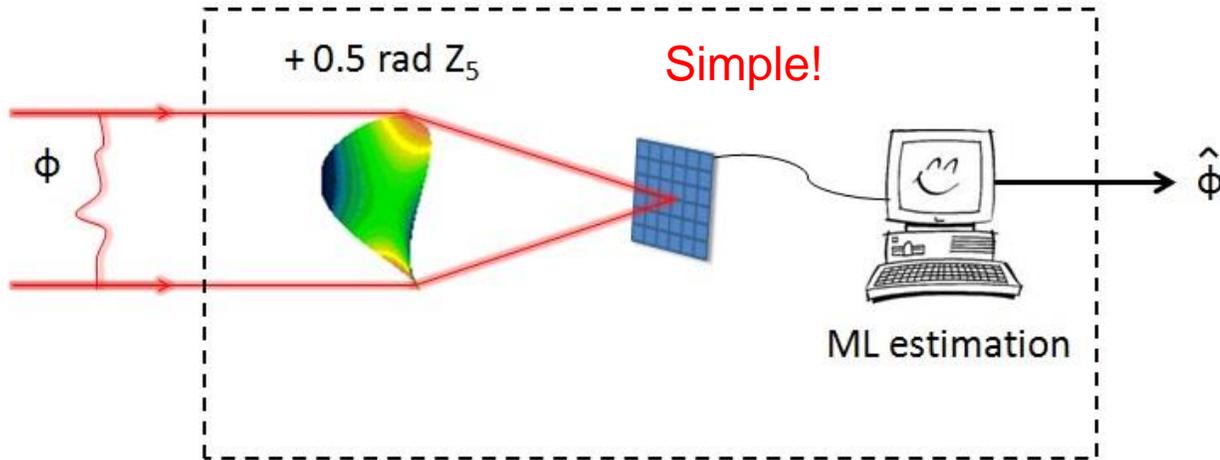
- H2RG camera
- 50 mas pixel
- Sensing band: H ($\lambda/D = 34$ mas) or Ks ($\lambda/D = 44$ mas)
- RON: 5 e- at 800 Hz, 2.8 e- at 100 Hz
- Negligible dark current



4x4 pixels read-out ≤ 800 Hz

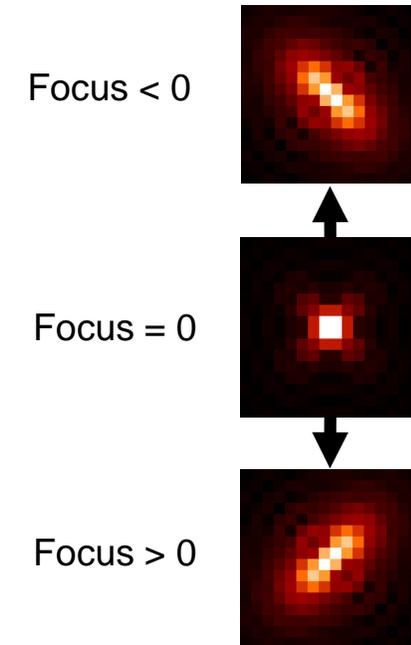
Centroid

LIFT: Linearized Focal-plane Technique



- Linearization \rightarrow Direct LO linear estimation (\equiv WCoG) \rightarrow **Fast**
- Full aperture focal-plane sensor
- Maximum Likelihood estimation \rightarrow **Optimized SNR**
- Astigmatism offset: removes the focus sign ambiguity

\rightarrow **Simple, fast, high SNR**



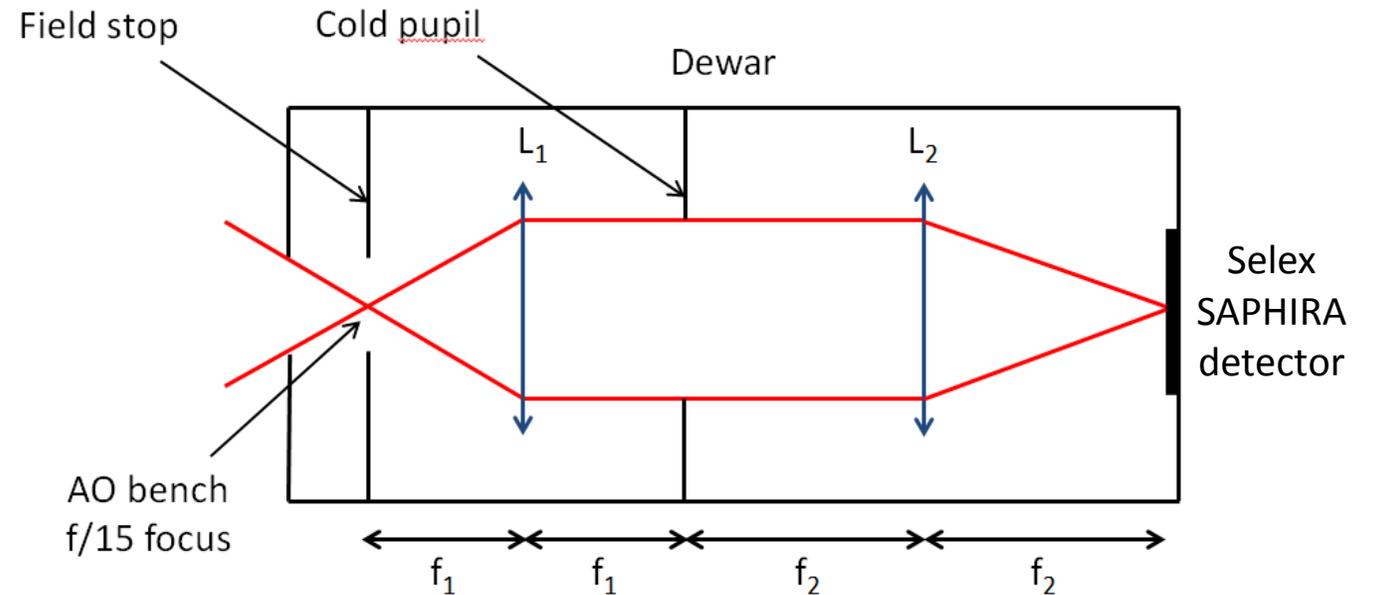
[Meimon10, Opt. Lett.]

LIFT on Keck II: conceptual design



- Only requirement: change $f/\#$ to get the desired sampling \rightarrow simple design
- Considered plate scales: **50 mas** (TRICK), **32 mas** (Nyquist/2 in H) and **17 mas** (Nyquist in H)
- RON = 0.8 e-, dark = 100 e-/s

- Best sampling?
- Better than TRICK?



- Computed from noise propagation coefficients
- Noise coefficients scaled with Strehl Ratio ($\Leftrightarrow n_{ph} = SR \times n_{ph_0}$)

[Plantet13&15, Opt. Exp.]
[Plantet16, SPIE]

Photon noise coefficient (signal)

Detector noise coefficient (other sources)

$$\sigma_{est}^2 = \frac{\alpha F}{\eta n_{ph}} + \beta \left(\frac{\sigma_{det}}{\eta n_{ph}} \right)^2$$

$$\alpha = \frac{\alpha_0}{SR}$$

$$\beta = \frac{\beta_0}{SR^2}$$

Read-out noise

Dark current noise

Background noise (thermal + sky)

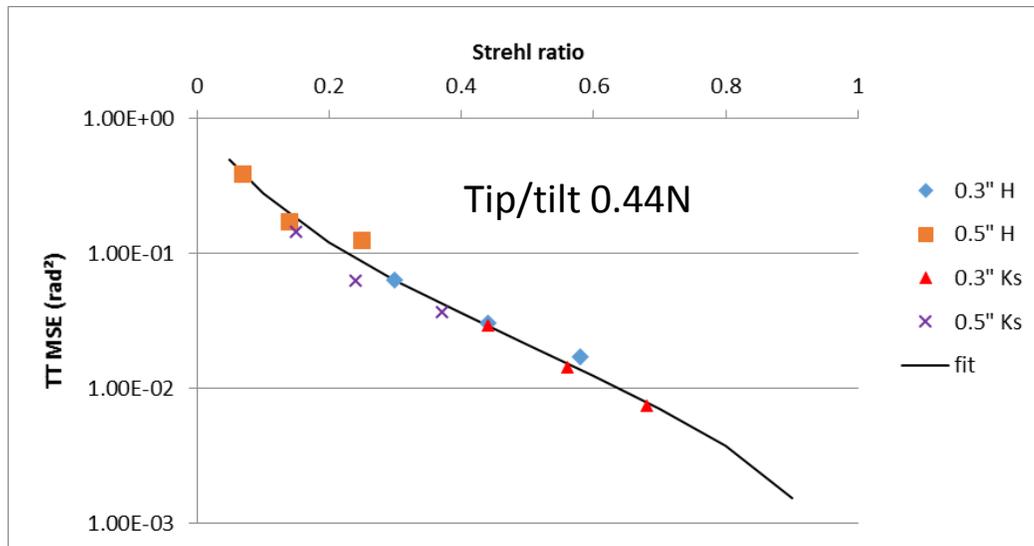
$$\sigma_{det} = \sqrt{\sigma_{ron}^2 + FG^2 i_{dark} T_{int} + FG^2 T_{int} \eta (F_{pix,th} + F_{pix,sky})}$$

APD gain

α_0, β_0 noise propagation coefficients at diffraction limit

Aliasing error

- LGS AO corrected phase screens from Fourier PSDs
- Estimation of turbulent tip/tilt/focus at 1 kHz
- Noiseless images
- NGS at 0", 20" or 40"

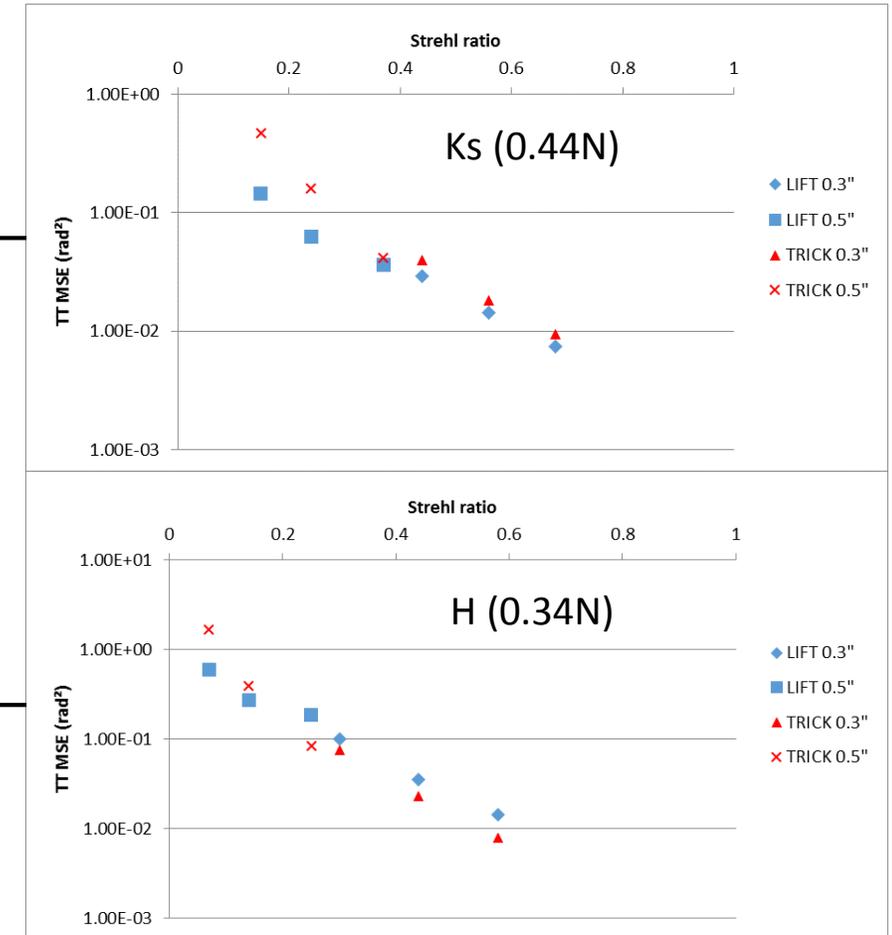


→ $MSE \sim f(SR)$

Quasi-independent of phase structure

Similar overall error

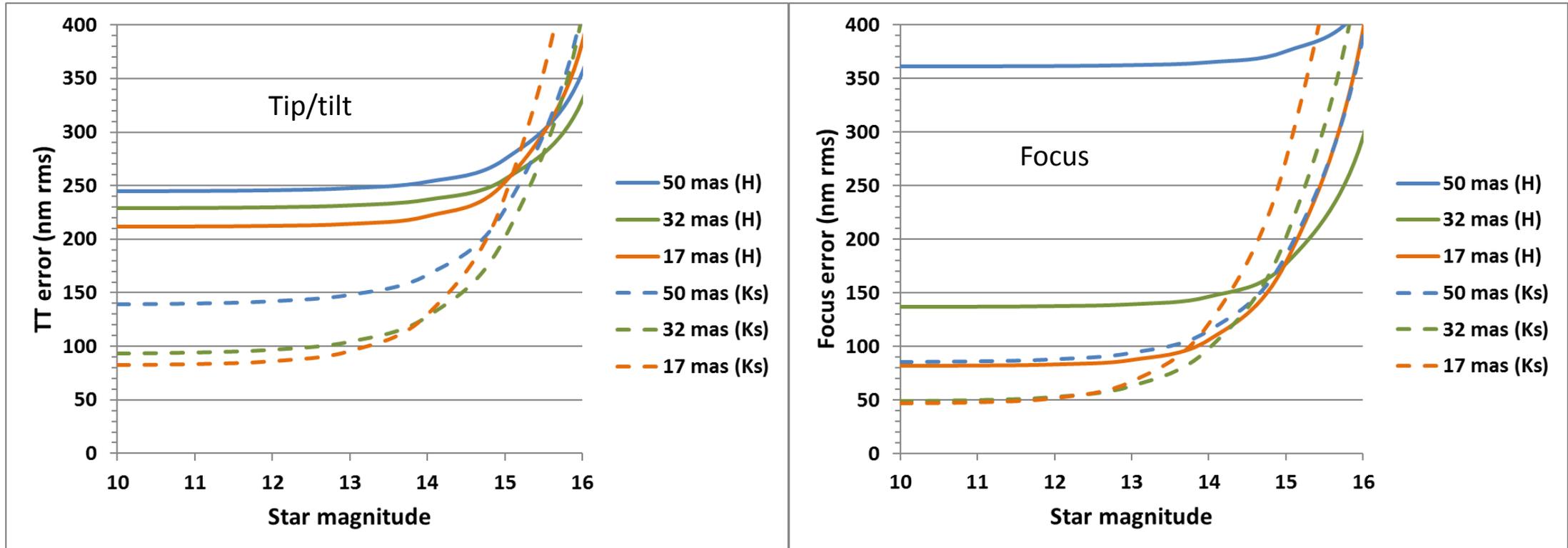
TRICK vs LIFT



Expected performance

Noise + aliasing @ 300 Hz

SR Ks = 25%, SR H = 8.5%



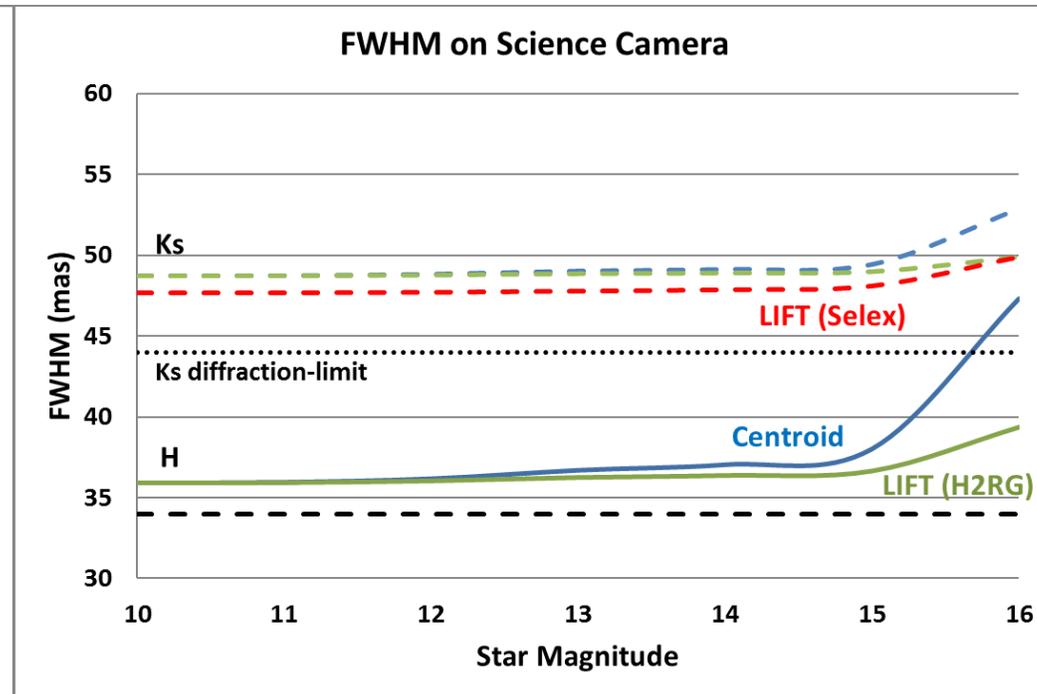
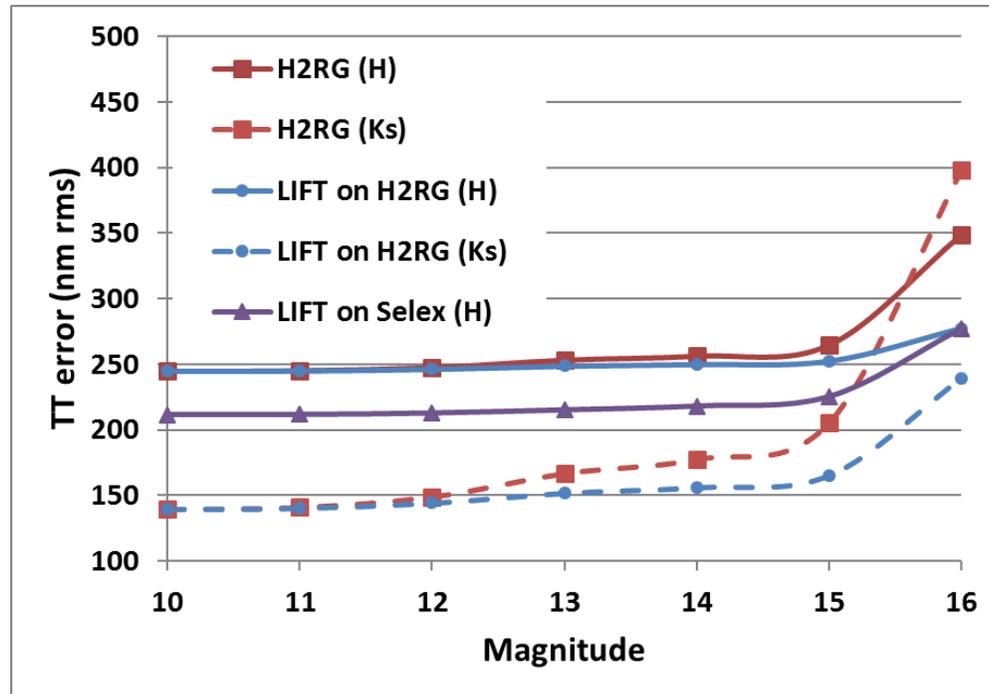
Low sampling (32 mas) better in Ks
Good sampling (17 mas) better in H
No sensing in Ks in new design → 17 mas on Selex

Comparison with TRICK



- Computation of noise coefficients for under-sampled centroid
- Same aliasing error for both sensors
- Frequency adapted to magnitude (800 Hz at 10, 100 Hz at 16)

SR Ks = 25%



- 1 magnitude gain on H2RG and Selex
- Slight gain (1 mas) on high flux FWHM with Selex

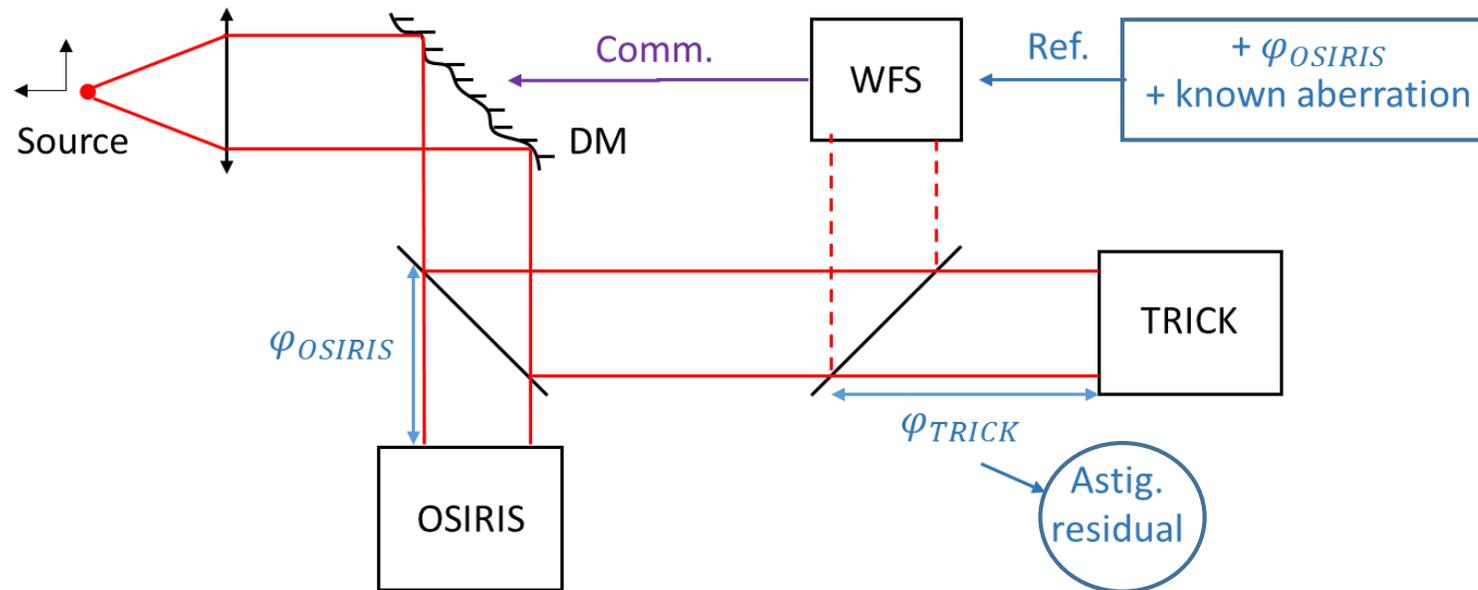
Selex pixel scale = 17 mas



Experiments principle

Goal: Demonstrate LIFT's ability to estimate tip/tilt/focus at very low sampling (< 0.5 N)

Astigmatism offset from NCPA (operational)

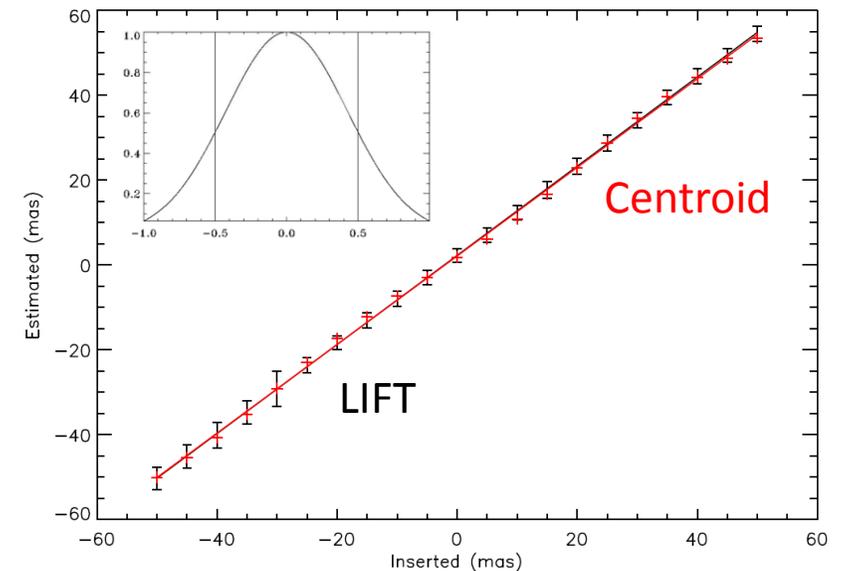
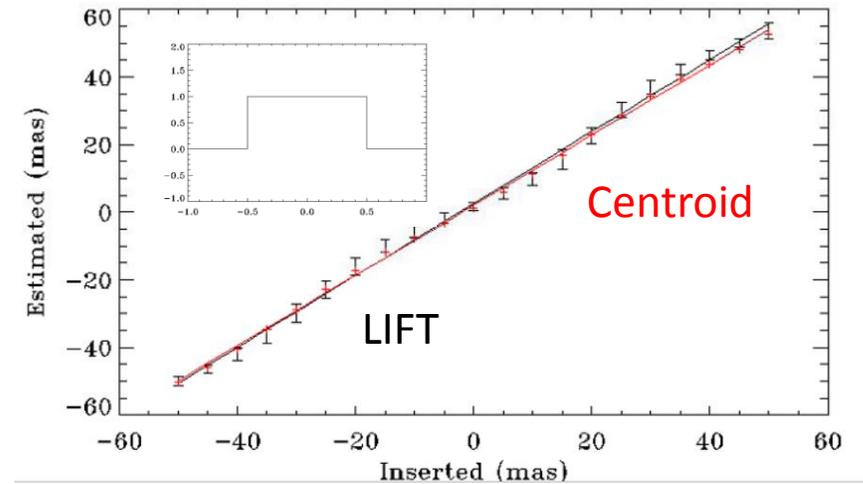
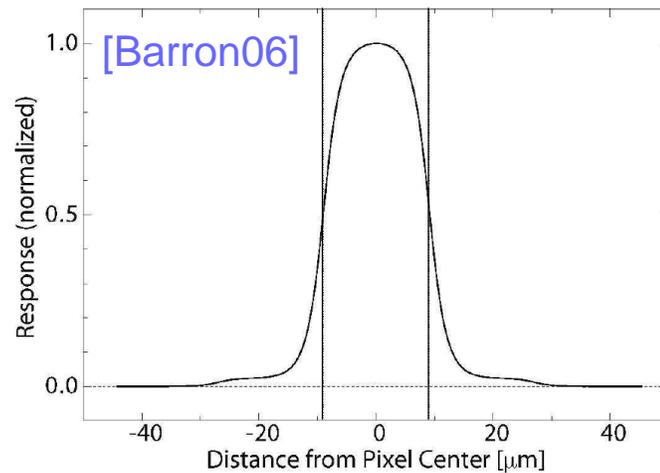


Tilt estimation and PSF model

Creation of image at sampling $S < \text{Nyquist}$:

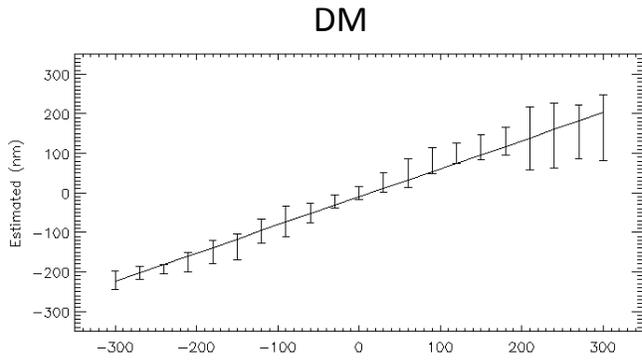
- PSF at kS : $PSF_0(x, y) = h(x, y) \times III_{l_{pix}/k}(x, y)$
- Convolution with (resized) pixel response:
 $PSF_1(x, y) = FT^{-1}\{FT[PSF_0(x, y)] \times \widetilde{f_{pix}}(ku, kv)\}$
- Sample the result at S : $PSF(x, y) = PSF_1(x, y) \times III_{l_{pix}}(x, y)$

H2RG pixel response:

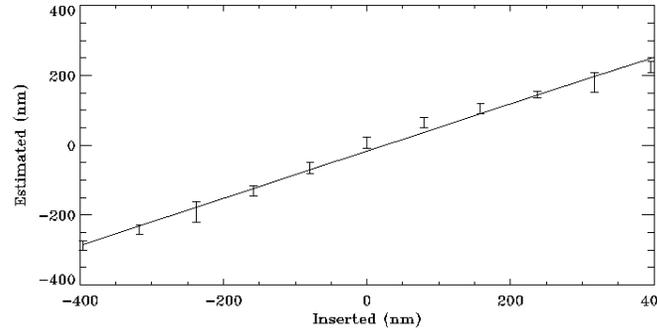


Estimation of focus/astig. on TRICK

Focus



Fiber

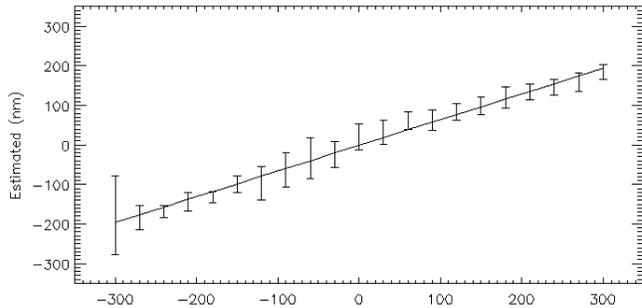


Astigmatism offset (found from first estimation):

30 nm Z5, -140 nm Z6

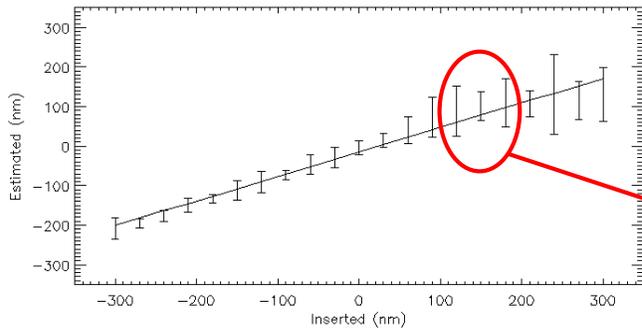
→ 145 nm (0.42 rad) total astigmatism

Astig 45°



- Linear estimation (rms \approx 15 nm)
- Enough astigmatism on TRICK's path for focus estimation

Astig 0°



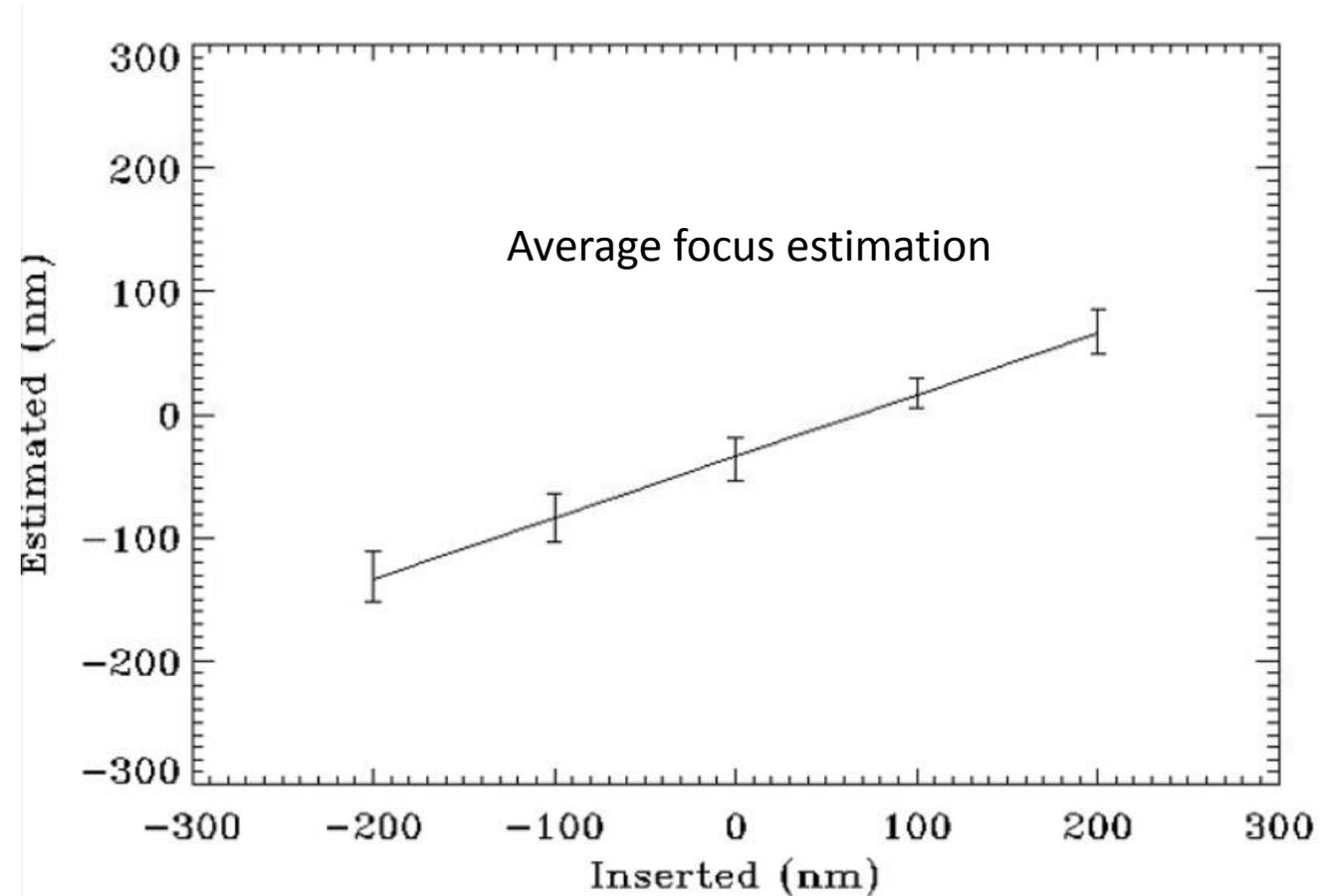
Astig \approx 0

Focus estimation at SR = 20%

- Random phase from astigmatism to 45th Zernike
- Normalization to SR = 20% (uniform)
- 40 occurrences/focus offset value

→ Linear estimation with bias ≈ 20 nm \approx error at diffraction limit

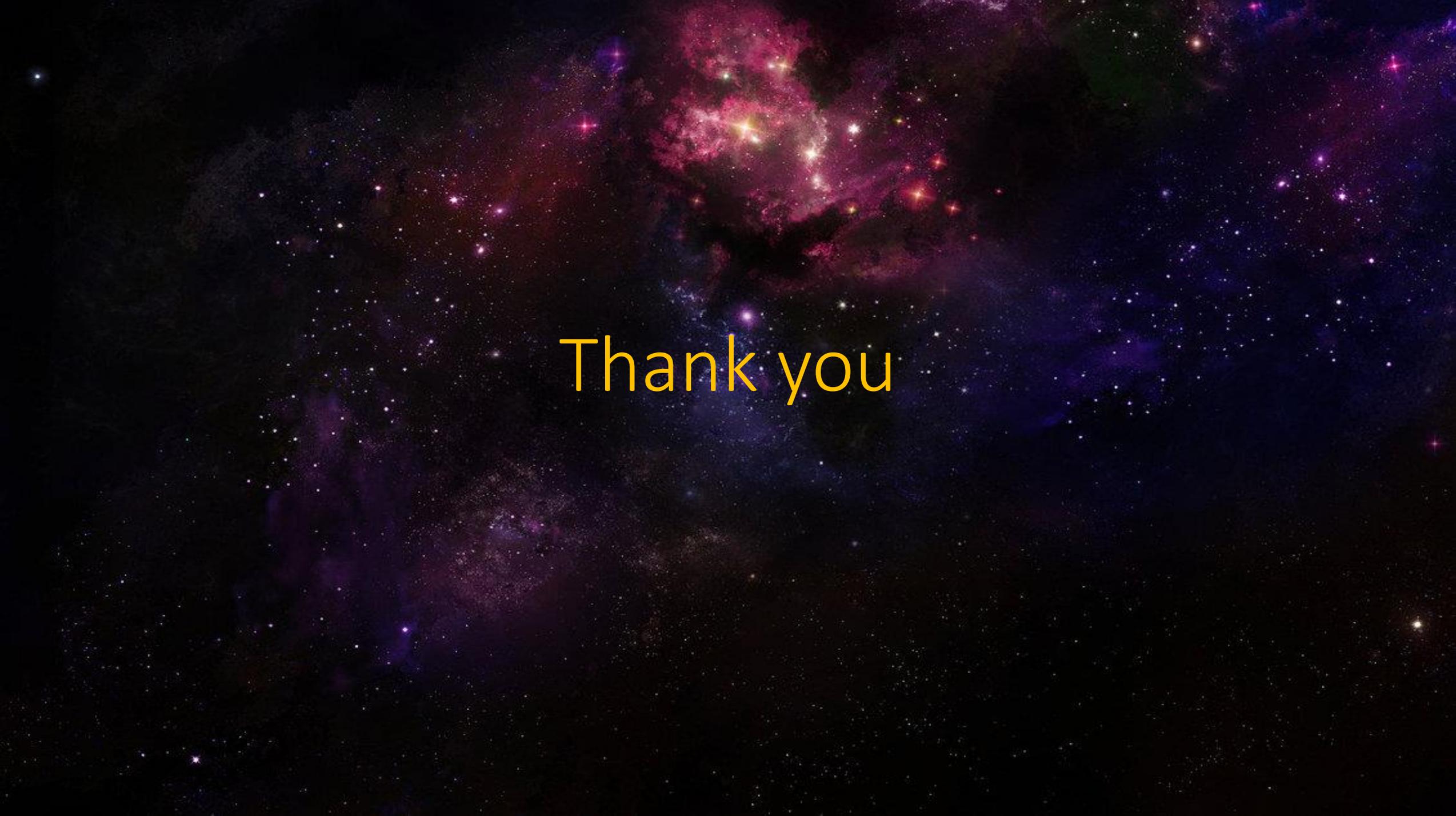
→ No additive bias on average estimation





Coming soon!

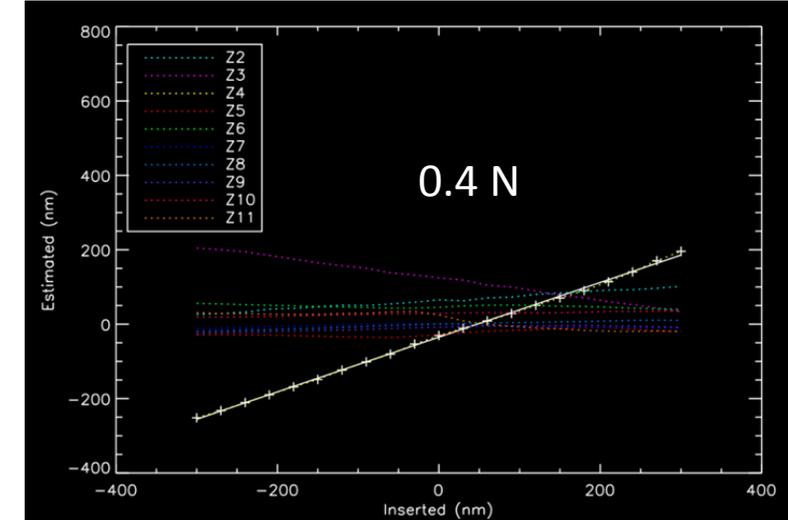
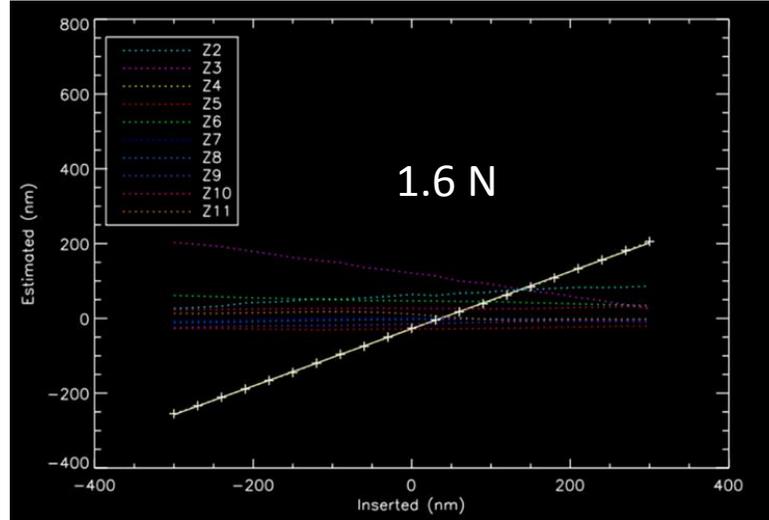
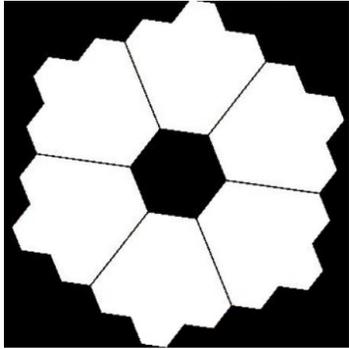
- Performance evaluation:
 - Well-sampled PSF = best trade-off noise/aliasing in H \rightarrow 17 mas for Keck II design
 - 1 magnitude gain on tip/tilt w.r.t TRICK in both H and Ks band (+ focus estimation)
- Experimental validation:
 - Linear estimation of tip/tilt and focus at very low sampling (0.44 Nyquist)
 - Focus estimation can be done with SR down to 20%
- Other and future work: [Poster Monday]
 - Comparison of LIFT and the pyramid for Keck II \rightarrow need for (well-sampled) LIFT confirmed
 - On-sky open-loop, then closed-loop, validation of LIFT



Thank you

Estimation with Keck pupil (NIRC2, Keck II)

Model (true):



Model:

