Status of PSF Reconstruction at Lick

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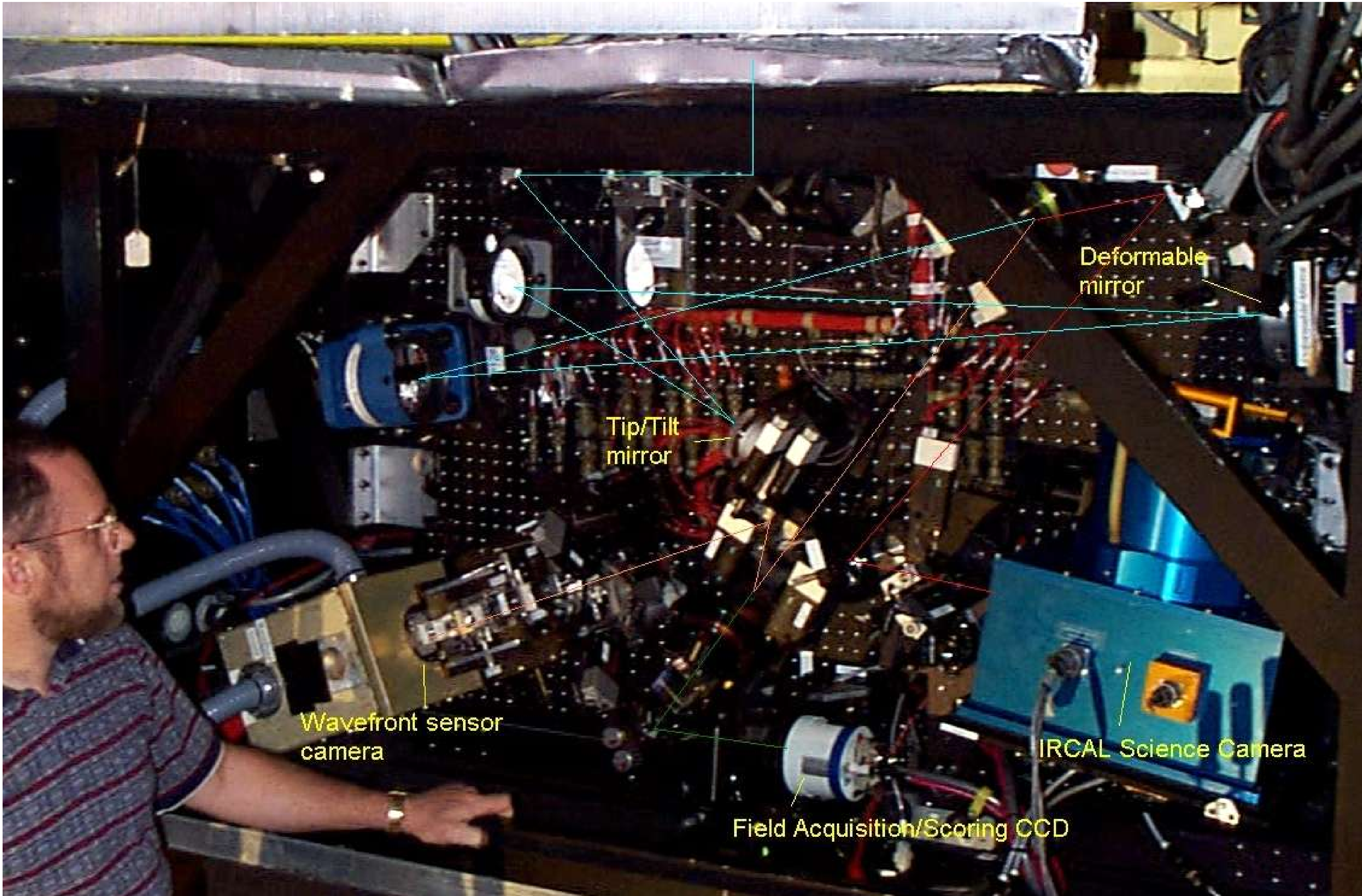
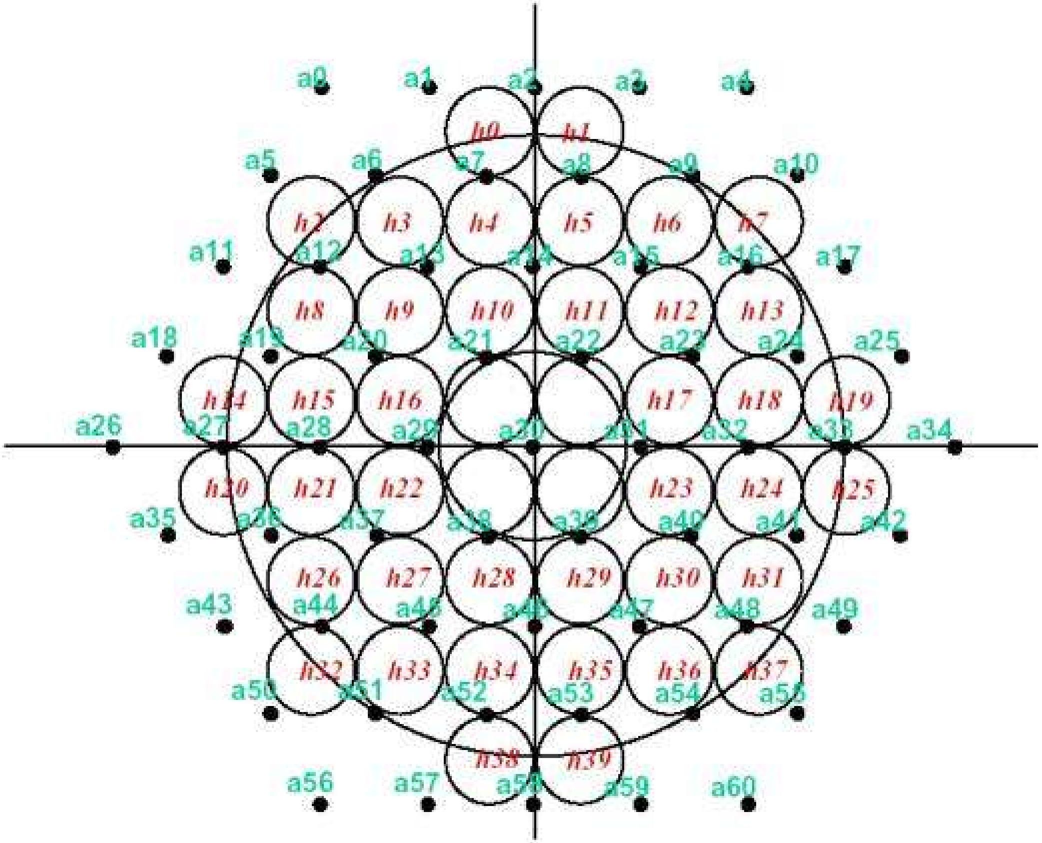
Workshop on AO PSF Reconstruction
May 10-12, 2004

Quick Outline

- Recap Lick AO system's features
- Reconstruction approach
- Implementation issues
- Calibration
- Current performance
- Future work


Deformable mirror
Tip/Tilt mirror
Wavefront sensor camera
IRCAL Science Camera
Field Acquisition/Scoring CCD

AO System Properties



- 40 Shack-Hartmann subaps
- square layout
- some partially illuminated
- 61 DM actuators
- triangular layout (no waffle)

AO System Properties

- Up to 1 kHz operation, 500 Hz typical
- Weighted-Least-Squares control matrix
- Laser Guide Star mode
- IRCAL camera Nyquist at 2.2 μm

PSF Reconstruction

- Véran method
- estimate OTF via mirror mode components and high-order component
- mirror mode portion: RTC residual wavefront estimate, considering noise, aliasing
- high order portion via simulated turbulence, scaled by r_0

PSF Reconstruction

- Simulate DM
  - actuators as Gaussians (amplitude, width)
- Simulate WFS (for high-order turb. effects)
- Model WFS noise
- Model loop transfer functions
- Choose mirror modes
- Use covariance matrices on modal basis to construct OTFs

More on Data Collection

- Mean pixel values used as input into pixel noise model (gaussian + poisson noise, linear variance vs. mean)
- Pixel values currently clipped at 0: so far looking at bright sources ($\mu >> \sigma$), so not a problem in noise estimation
- Pixel covariance collection
  - small effect, but large offset reference centroids can cause covariance in X, Y slope measurements
  - easy to collect these data (not many CPU cycles)

WFS Noise

- want an estimate of σ_{WxWy}, noiseless meas cov (2nd order expansion)
- assume noise uncorrelated between SH subapertures
- calibrate pixel noise model on twilight sky data
- empircal model for noise variance vs. mean in each pixel
- in a given subap,
  - $a_i = p_i + n_i$ $x = [1, 1, -1, -1]$ $y = [1, -1, 1, -1]$
  - $w_x = \Sigma x_i a_i / \Sigma a_i = \Sigma x_i (p_i + n_i) / \Sigma a_i$ $W_x = \Sigma x_i p_i / \Sigma p_i$
  - $s = \Sigma \langle a_i \rangle$ $r_x = \Sigma x_i \langle a_i \rangle$
  - noise cov. $\sigma_{wxwy} - \sigma_{WxWy} \sim= s^{-2} \Sigma (x_i - r_x / s)(y_i - r_y / s) \sigma_{ni}^2$

Mirror Mode Selection

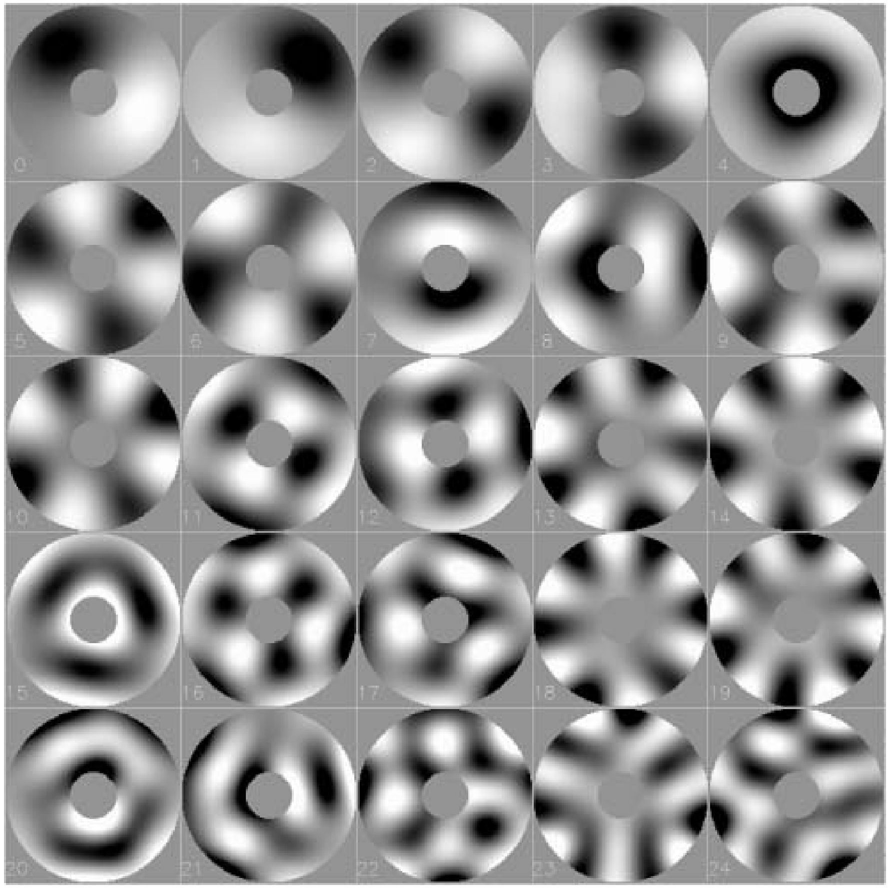
- Wavefront basis functions orthonormal over pupil
- Restrict to space of wavefronts produced by mirror
- Further restrict to space of wavefronts to which the WFS is sensitive
- Some subapertures are less sensitive (partial pupil obscuration)...

Mirror Mode Selection

- D is system interaction matrix (push matrix)
- SVD of $D^T WD$ gives WFS modes in actuator basis
- Remove low SV directions in actuator space to which WFS is insensitive (invisible WFS modes)
- Construct spatial representation of visible WFS modes with simulated actuator influence functions

Mirror Mode Selection

- Construct matrix of wavefront inner products (over pupil) of WFS modes
- Eigenvectors of this matrix are the mirror modes



Simulations

- 1000 phase screens (D/r_0=1)
- subtract mirror mode component
- Use mirror mode component covariance as emprical values of Kolmogorov model in modal basis
- Use high-order component for structure f'n calc
- Use WFS response to high-order component to extract aliasing covariance

Implementation Considerations

- code in IDL/C, system glue in Python
- U_{ij} function storage
  - for N modes, N(N+1)/2 unique functions
  - for 128^2 pupil grid, 256^2 OTF grid
  - want in RAM

Calibration: DM

- Ideally one would have a map of OPD
- Currently simulate influence functions with gaussians, fit parameters to system interaction matrix D
  - couples with WFS simulation
  - partially-illuminated subaps?
- voltage response temp. dependent - timescales?
- need to improve this calibration

Calibration: WFS

- WFS scale
  - set by angular size of WFS detector pixels
  - bootstrap with science camera scale

Calibration: WFS

- WFS spot gain
  - larger spot size reduces tilt sensitivity of subaps
  - scale RTC estimate of $C_{\varepsilon\varepsilon}$ by g_{spot}^{-2} – large effect!
  - try to measure:
    - take open-loop and closed-loop temporal power spectra. ratio will give the correction transfer function H_{cor} (f, g_{eff}) (disturbance rejection)
    - inject small tip/tilt dither, synchronous phase with WFS readout (but smaller than diffraction limit)
    - other?

Calibration

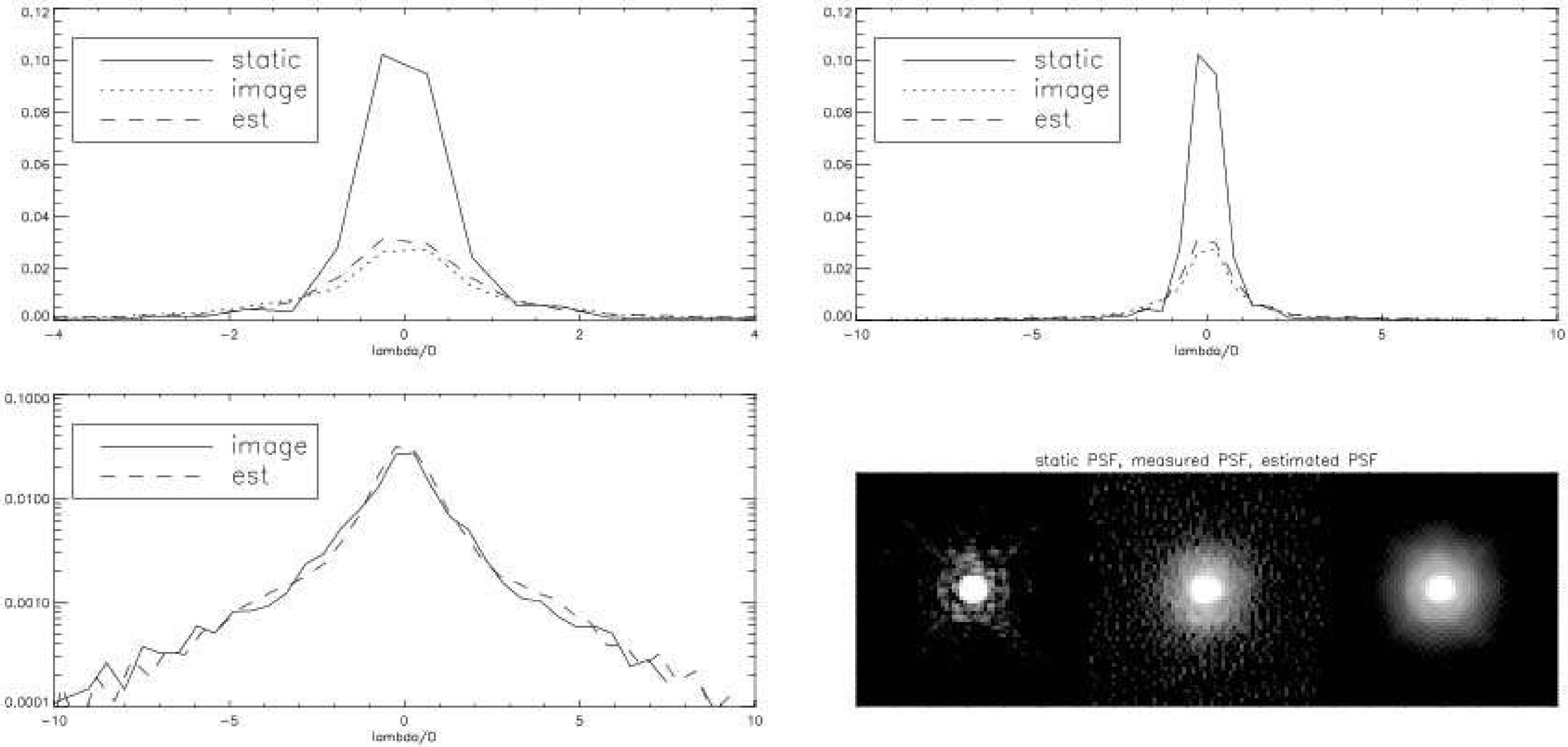
- Control loop dynamics
  - delay is main unknown
    - profile RTC code
    - fit as parameter in H_{cor} measurement (power spectra ratio)
    - Lick: about 1.4 ms; significant for 1 kHz operation
- Quasi-static OTF
  - internal source (doesn't get primary/secondary aberr.)
  - well-corrected on-sky measurements
  - what are the variation timescales?

Performance

- 10 sec exposures of bright binary stars (mV ~ 7)
- 1.5 to 4 arcsec separations
- narrow-band (Brγ)
- extract image PSF with Starfinder; normalize with box 4.8 arcsec on a side (64 pixels)
- Static OTF from internal source only

Performance

- Calibration problems affecting reconstructed PSF



Performance

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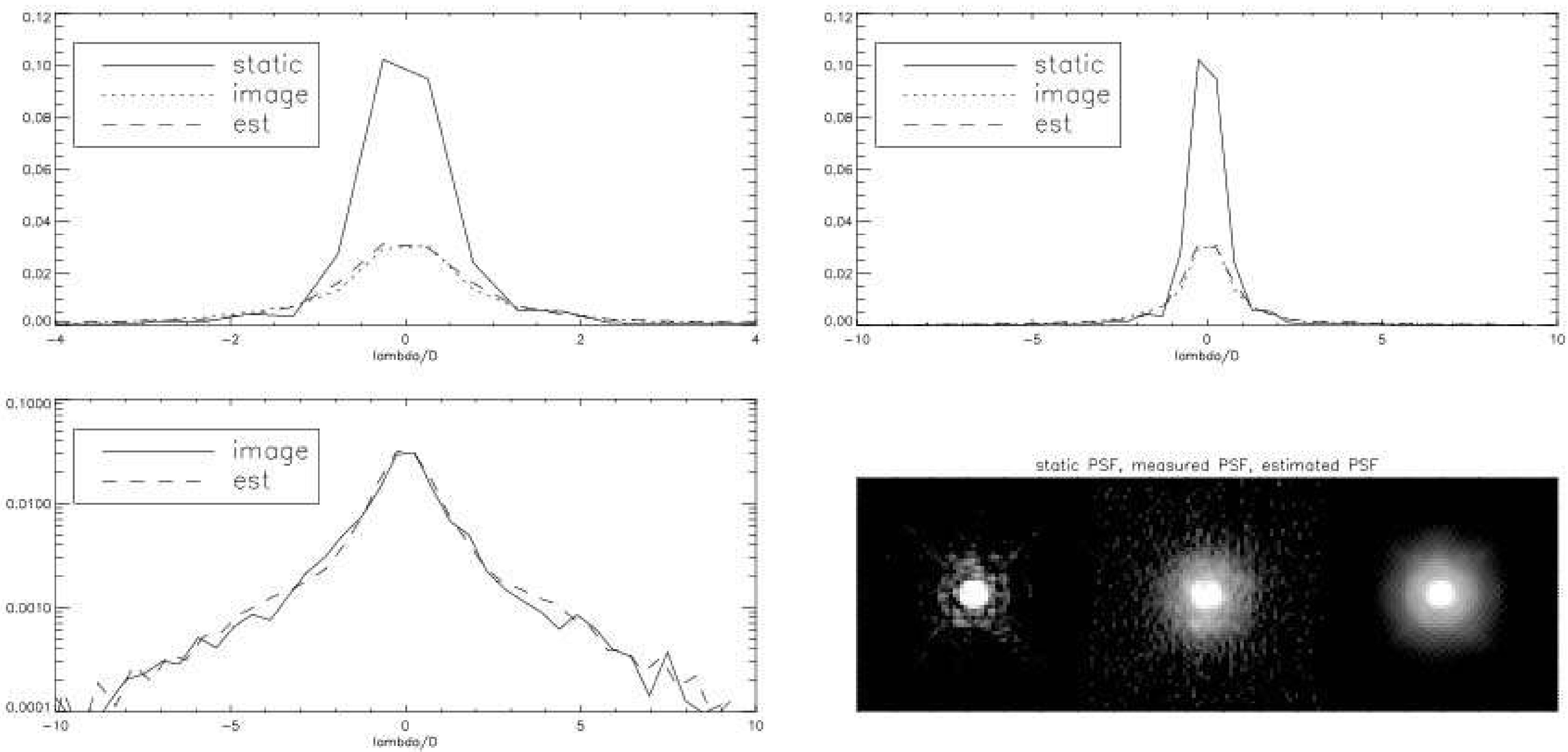

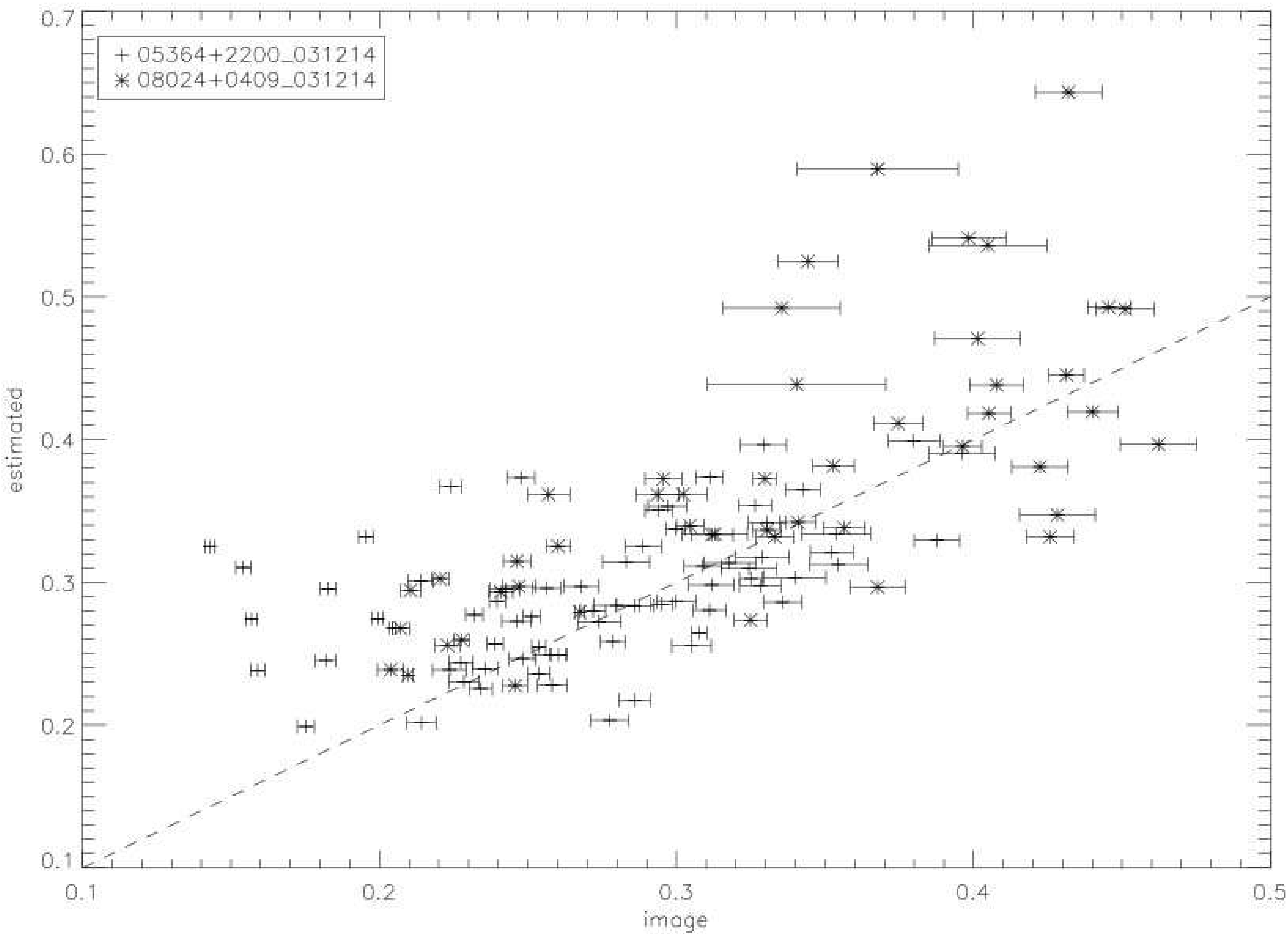

05364+2200_031214
08024+0409_031214
estimated
image
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.1
0.2
0.3
0.4
0.5

Miscalibration

- How does miscalibration affect reconstructed PSF?
- Spot gain lowers estimate of residual phase from actual: overestimate Strehl
- DM scale affects r_0 estimate. Bright sources have aliasing as major component...

What's Next

- In-depth analysis of data set
- How do we best calibrate our dominant error sources?
- Integrate other centroid routines (4x4, correlation)
- Integrate LGS mode TT sensor data