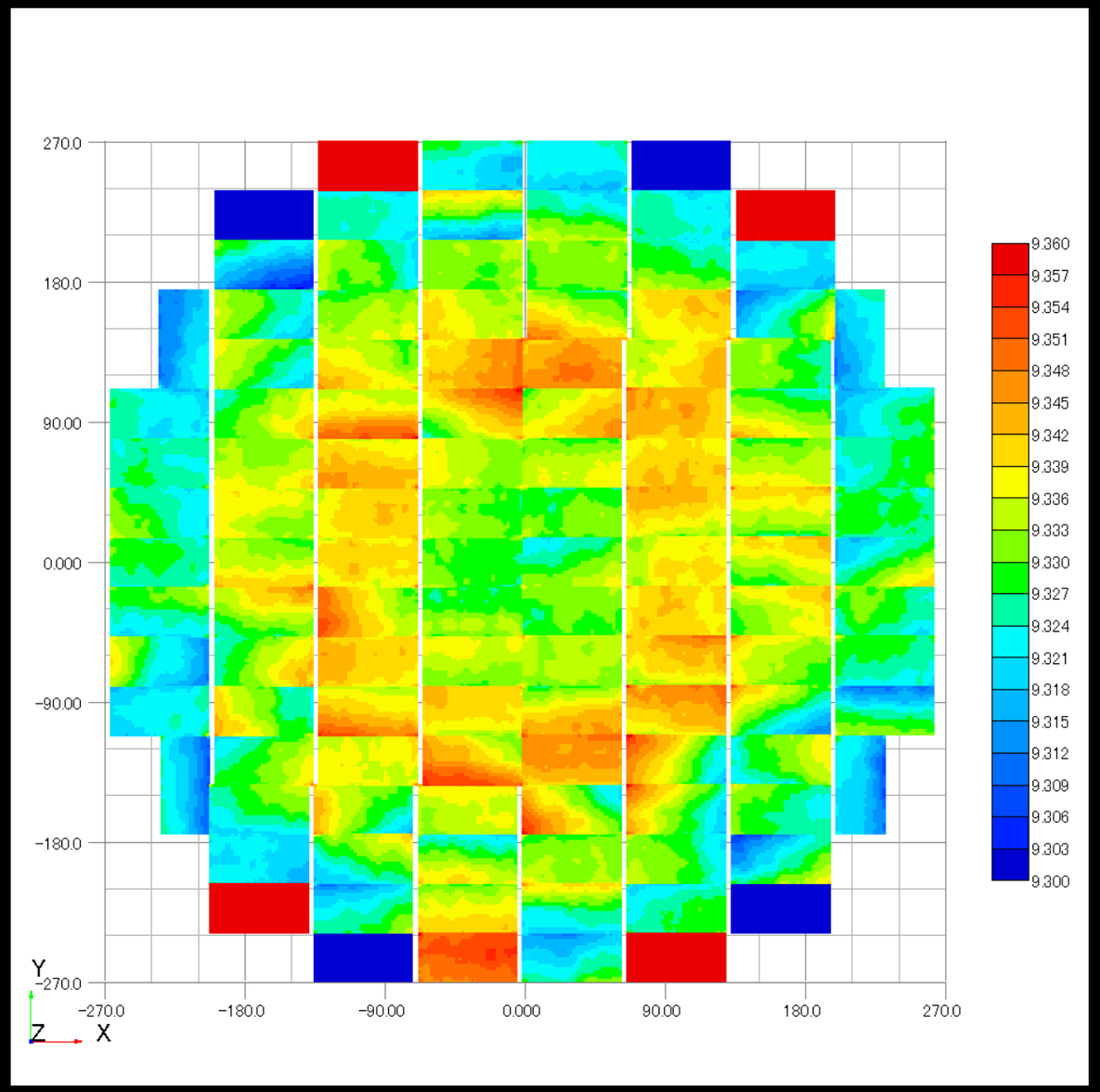
LSST PSF modeling plans

Josh Meyers

PSF modeling challenge: discontinuities

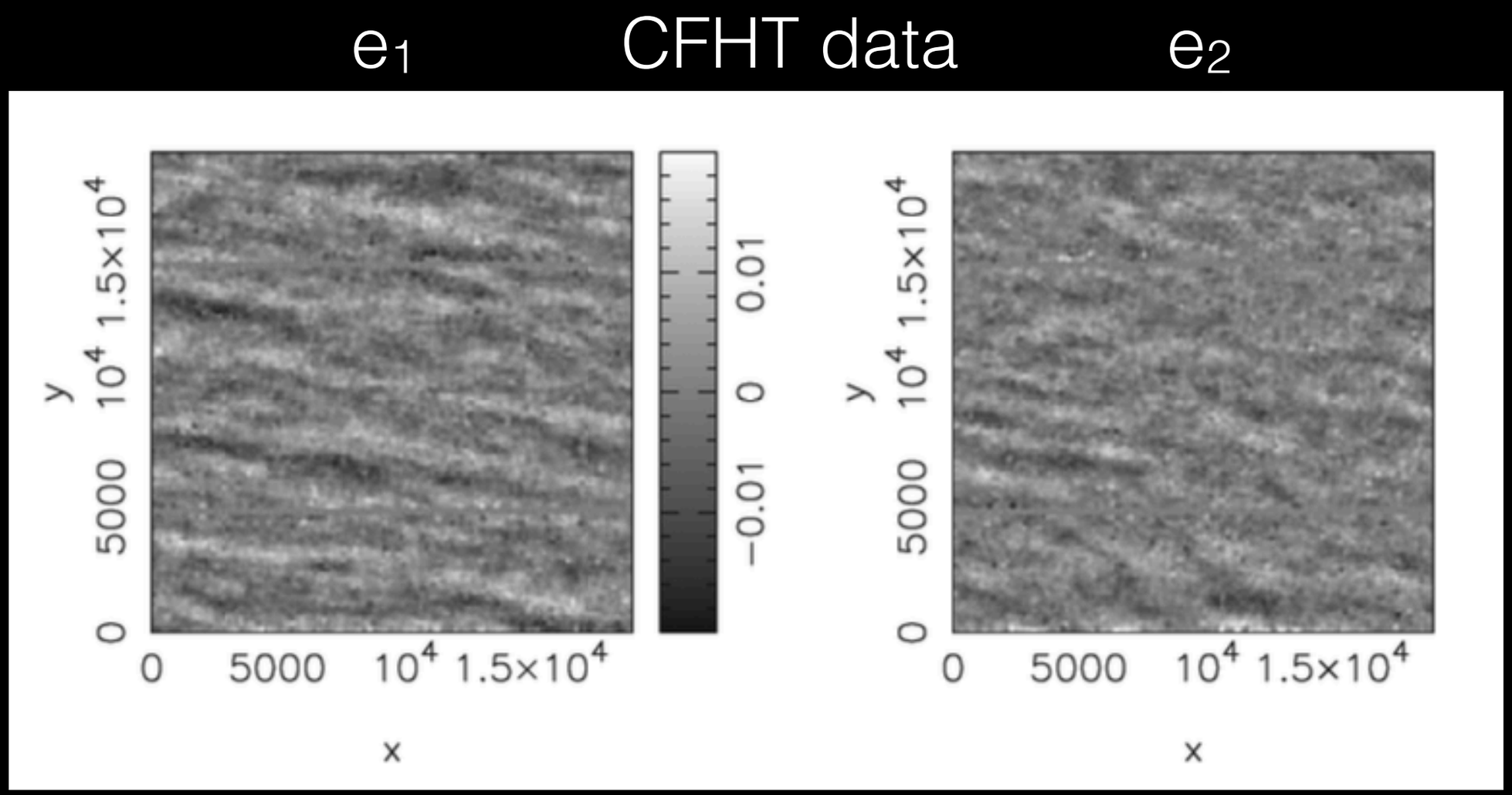
- CCD gaps => PSF discontinuities
- Current schemes restricted to individual CCDs

HSC height map



PSF modeling opportunity: spatial correlations

- Atmospheric PSF often contains interesting spatial correlations
- Most interpolation algorithms can't take advantage of this



Heymans++12

A modular PSF model

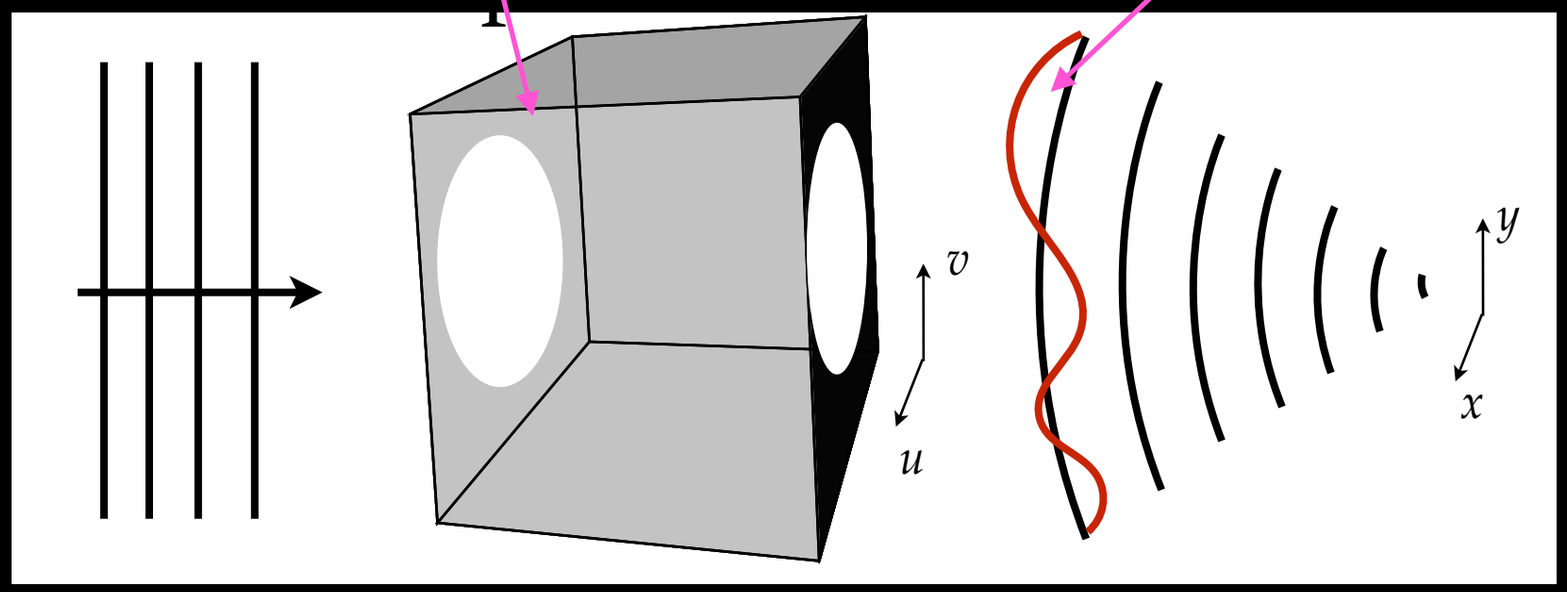
- PSF = Convolve(optics, ccd, atmosphere)
  - Formally true in the long exposure limit
    - (with caveat that not all ccd effects are convolutions)
- Incorporate discontinuities into physical optics model
- Small number of parameters to capture the optics (could help with undersampling)
- Allows one to interpolate the atmosphere over full field of view.

Fourier optics model

$$I(\vec{\theta};\vec{x}) \propto \left| \mathcal{F}\left[\underline{P(\vec{\theta};\vec{u})} \exp\left(\frac{-2\pi i}{\lambda} \underline{W(\vec{\theta};\vec{u})} \right) \right] \right|^2$$

pupil illumination

wavefront



$\vec{\theta}$ = sky

$\vec{x}$ = image

$\vec{u}$ = pupil

$$W(\vec{\theta};\vec{u}) = W_{\mathrm{ref}}(\vec{\theta};\vec{u}) + W_{\mathrm{state}}(\vec{\theta};\vec{u})$$

Fixed figure errors, chip offsets, …

Modelable for every exposure,smooth

Building W_{ref}

- Use high fidelity model.
- or measure directly.
- Piston camera to turn into wavefront sensor.
- Use multiple measurements of W and knowledge of form of W_{state} to isolate W_{ref}.

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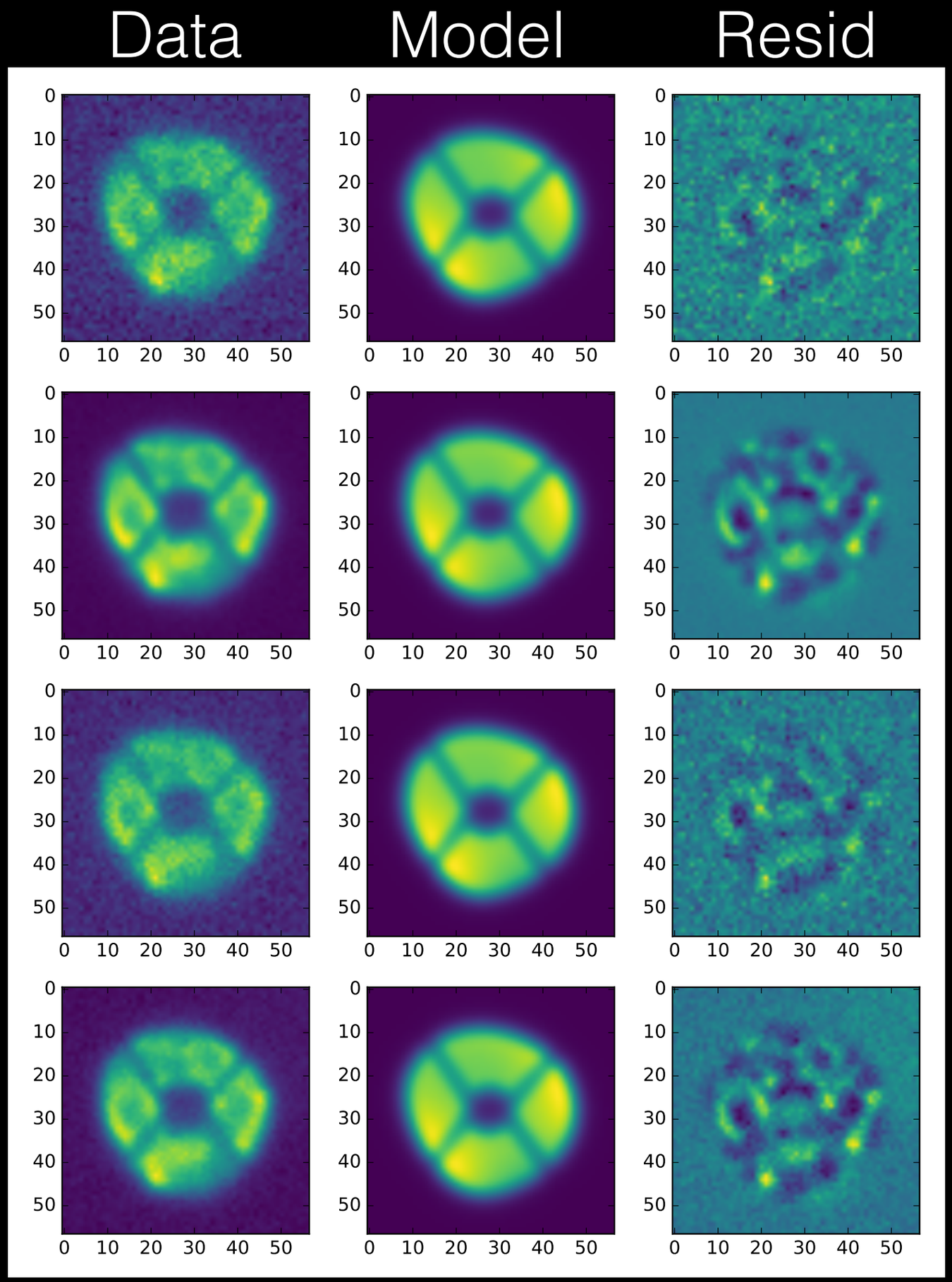
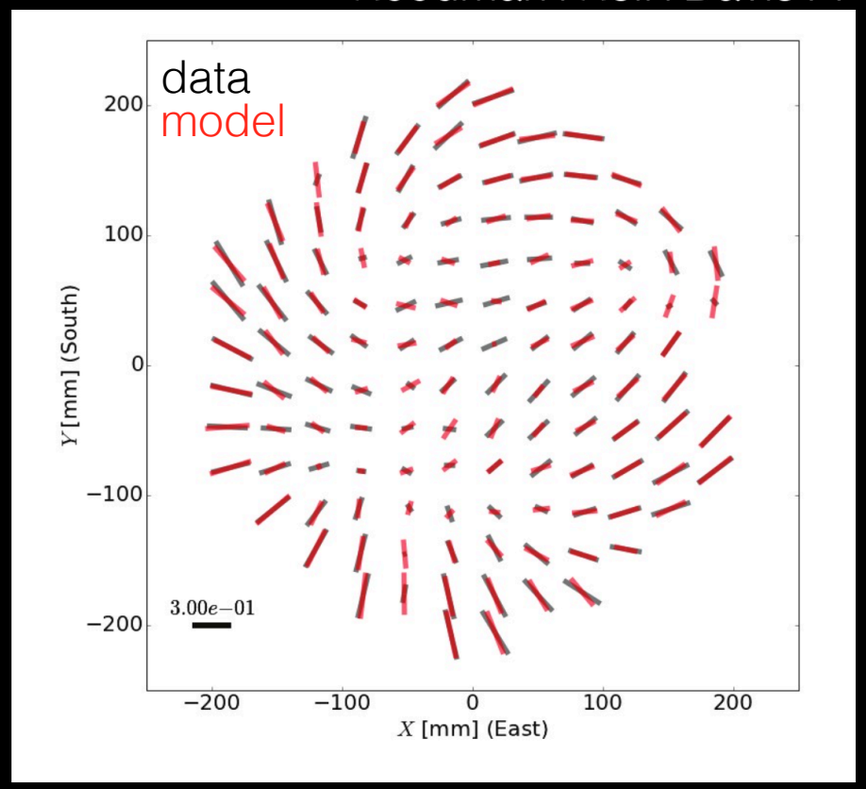


HSC donuts

Inferring the optical state

- Can infer from WF sensors plus detailed model of sensitivity to doc (hexapods + bending modes) (See work by Bo Xin).
- Information in the science CCDs?
  - Many more stars but more contaminated by atmosphere.

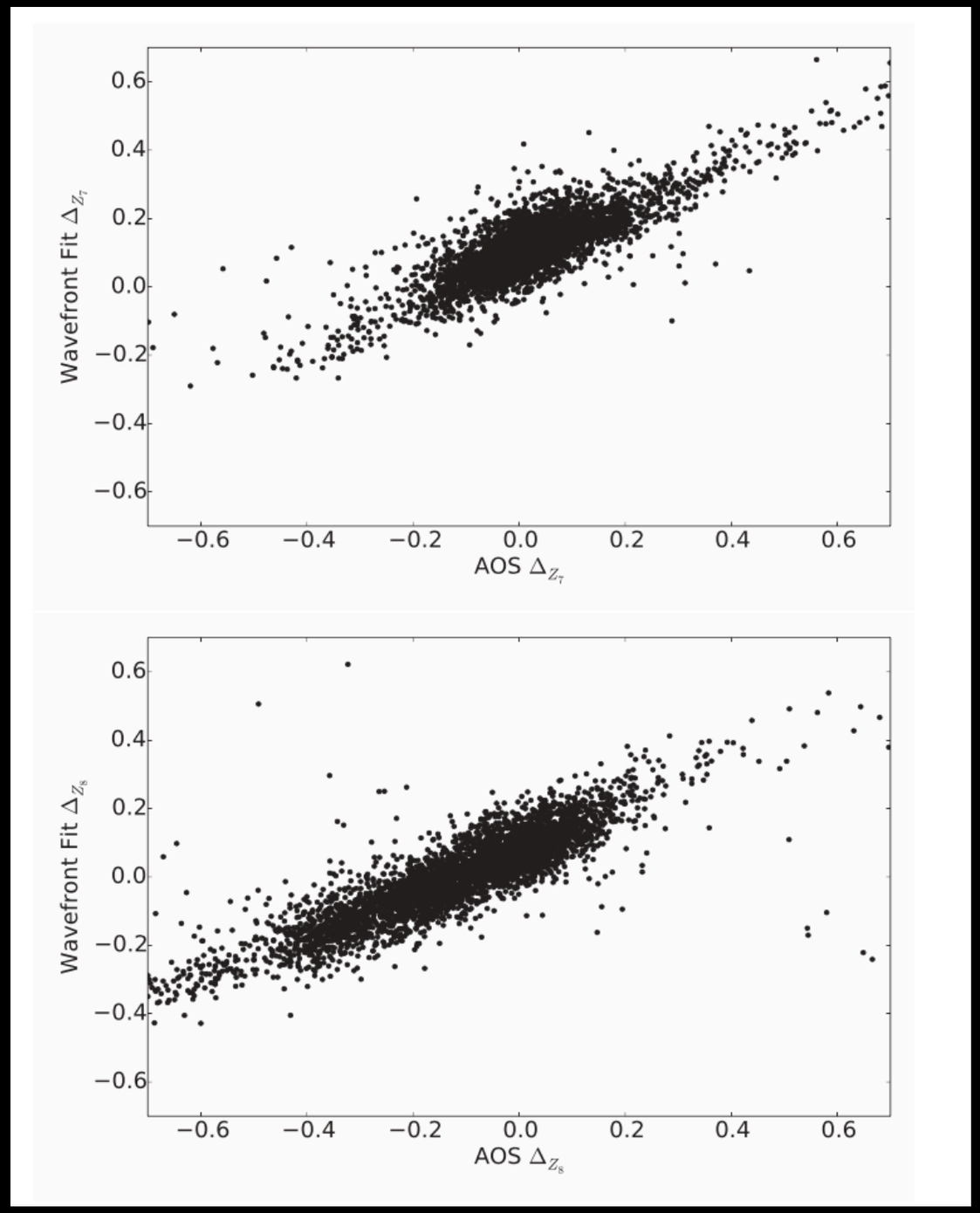
Roodman+Reil+Davis14



DECam optical state inference

Roodman+Reil+Davis14

WF inferred from in-focus stars



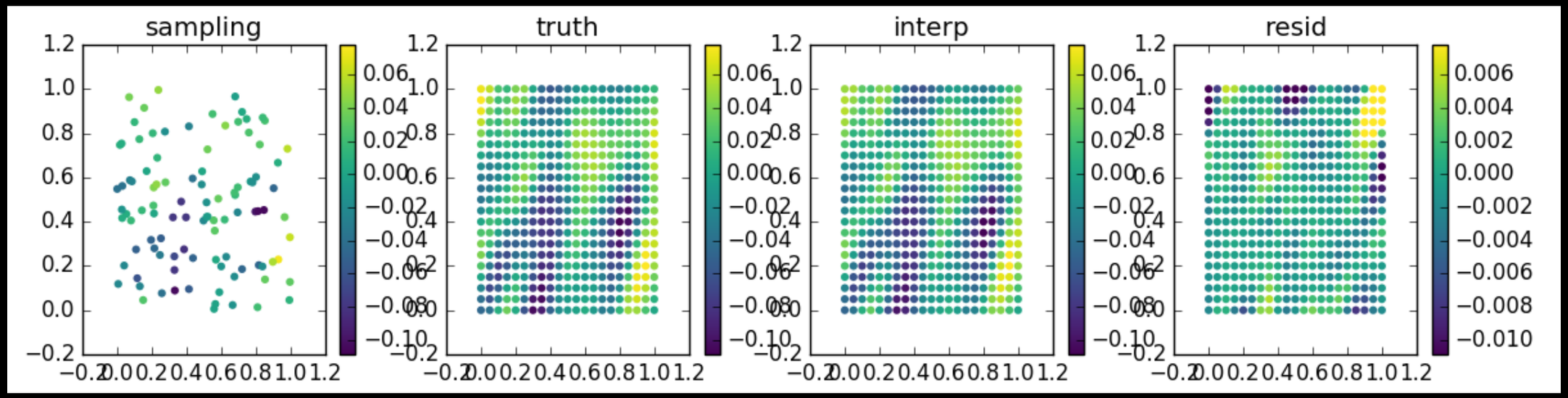
WF sensor measurement

From optics to atmosphere

- “Deconvolve” observed stellar images by optics PSF model
- “Deconvolve” probably really means fitting a model.
  - Model for an individual star is parametric:
    - Elliptical Kolmogorov (size, e1, e2)
    - Pixel basis, Gauss-Hermite coefficients.
    - PCA
    - …
  - Field-dependence may or may not be parametric:
    - Parametric: Polynomial, Spline
    - Non-parametric: Gaussian Process

Modeling the atmosphere with a Gaussian Process

- A GP models the spatial *covariance* between PSF stellar parameters instead of stellar parameters directly.
    - Prediction parameters are a linear combination of training stellar parameters. Weights are informed by covariance and training parameter uncertainties.
    - Implies that stellar fits are done independently.
- Pro: more flexible than polynomial fitting. Uses spatial covariance.
- Con: more flexible than polynomial fitting. Less regularization? Sensitivity to outliers?



Research questions

- How correct is convolution factorization? I.e., how close are we to the long exposure limit?
- Do we regularize and how? In the individual stellar fits? In the FoV dependence?
- How can we develop priors for the Gaussian Process model? Commissioning data (high stellar density fields)? Conditioned on external data?, e.g. DIMM, wind? other?
- How desirable is a probabilistic PSF?
- How to implement chromatic corrections?