LSST PSF modeling plans
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PSF modeling challenge: discontinuities

- CCD gaps \(\Rightarrow\) PSF discontinuities
- Current schemes restricted to individual CCDs
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

- \( \text{PSF} = \text{Convolve}(\text{optics, ccd, atmosphere}) \)
- 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

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

pupil illumination
wavefront

\[
W(\vec{\theta}; \vec{u}) = W_{\text{ref}}(\vec{\theta}; \vec{u}) + W_{\text{state}}(\vec{\theta}; \vec{u})
\]

Fixed figure errors, chip offsets, …
Modelable for every exposure, smooth
Building $W_{\text{ref}}$

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

\[ W(\vec{\theta}; \vec{u}) = W_{\text{ref}}(\vec{\theta}; \vec{u}) + W_{\text{state}}(\vec{\theta}; \vec{u}) \]
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.
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?