Image differencing

Status and plans for LSST alert pipelines

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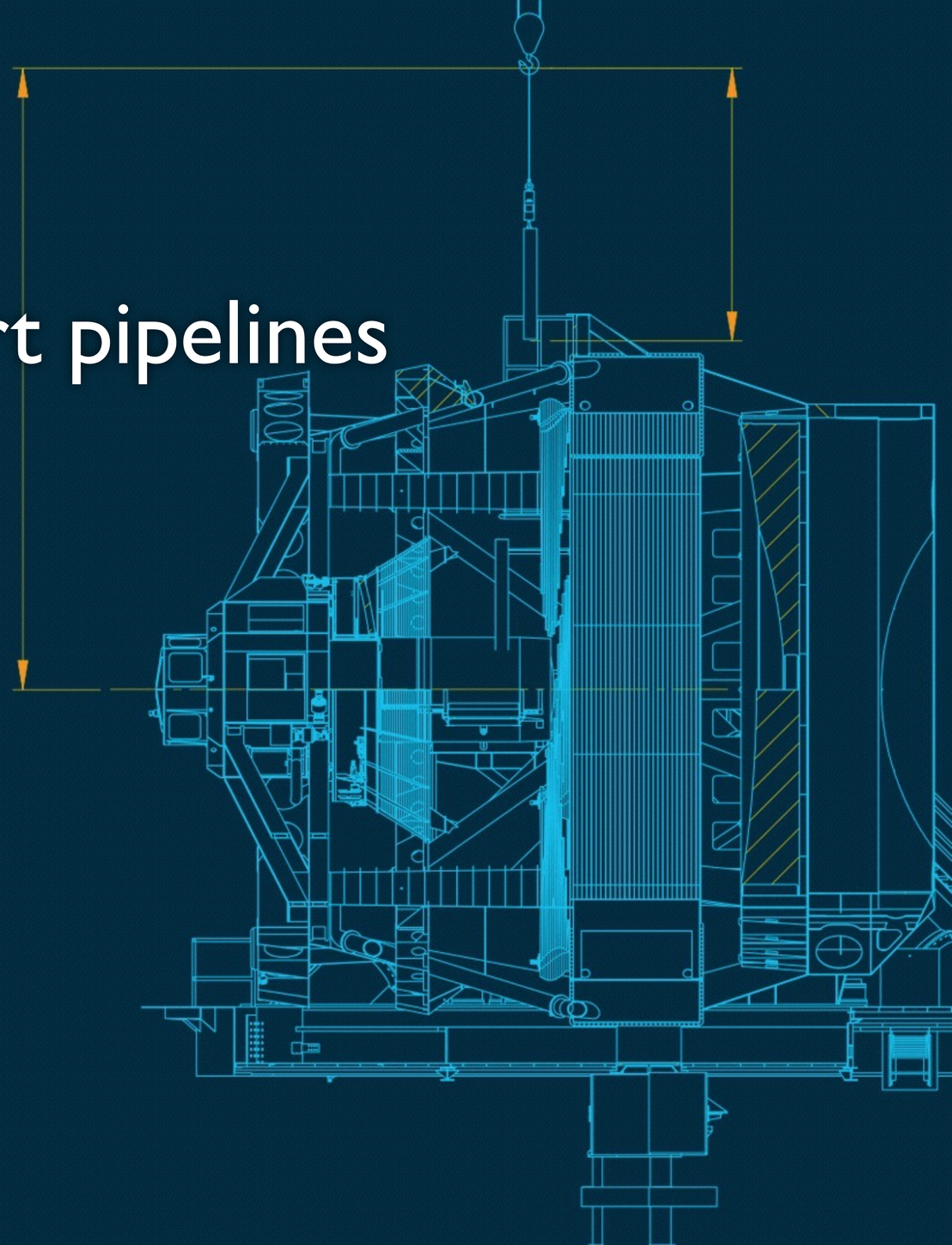
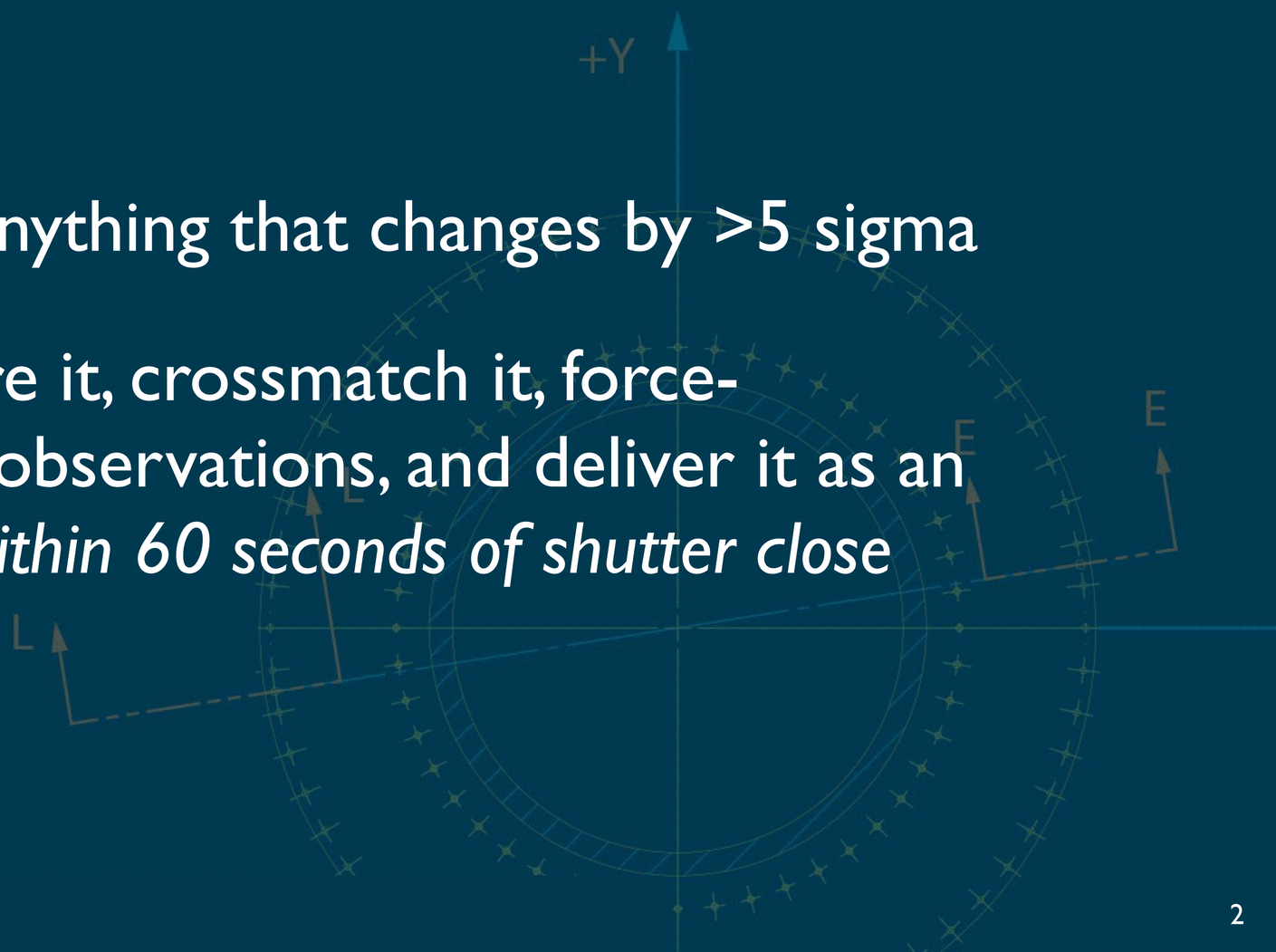
LSST DM Research Scientist
University of Washington



Large Synoptic Survey Telescope

Level 1: Nightly Processing

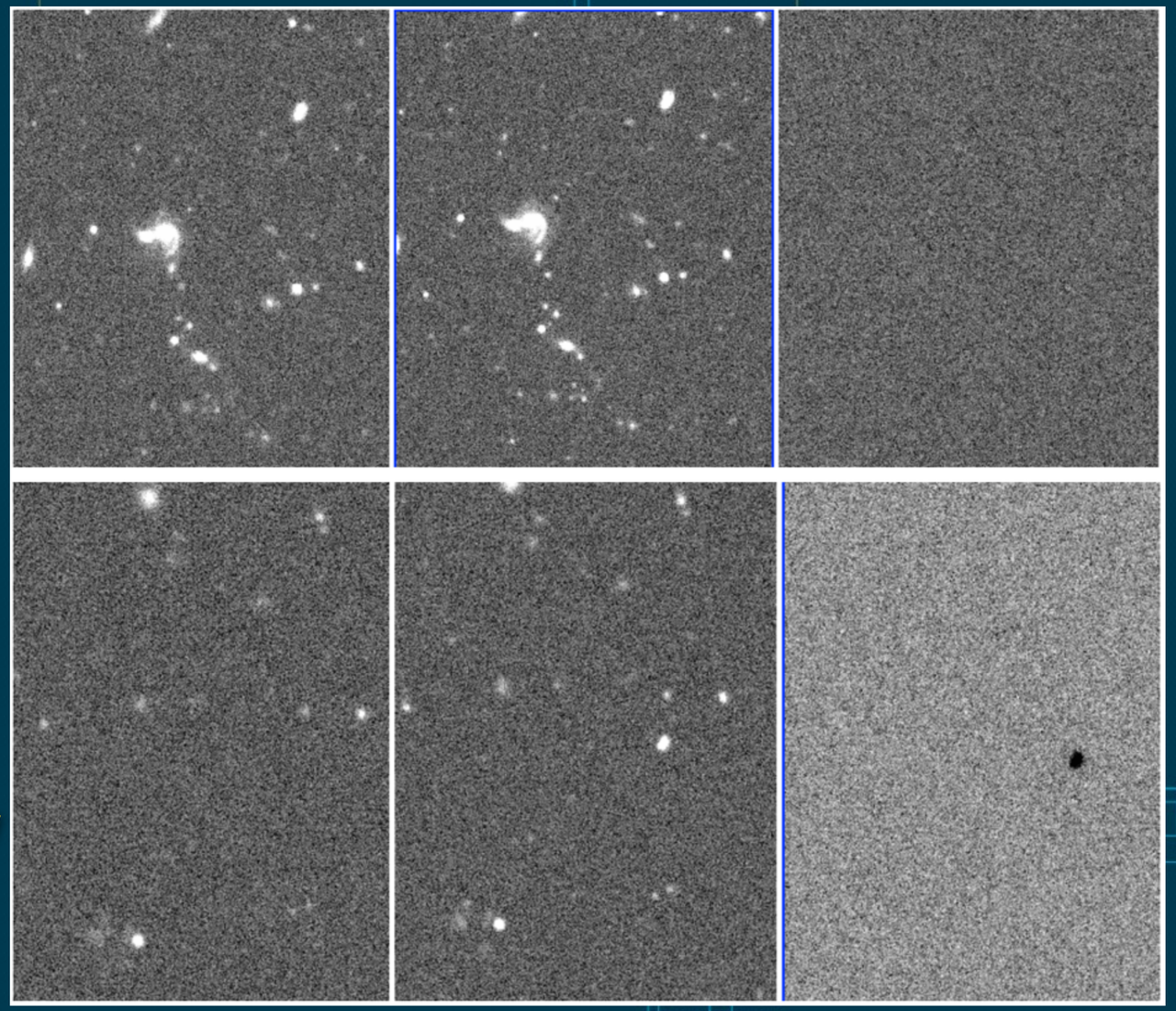
- Detect and measure anything that changes by >5 sigma
- We will find it, measure it, crossmatch it, force-photometer previous observations, and deliver it as an alert to the brokers *within 60 seconds of shutter close*



State of `ip_diffim` as of summer, 2016

A fast implementation of the Alard & Lupton optimal image subtraction method (1998, 2000)

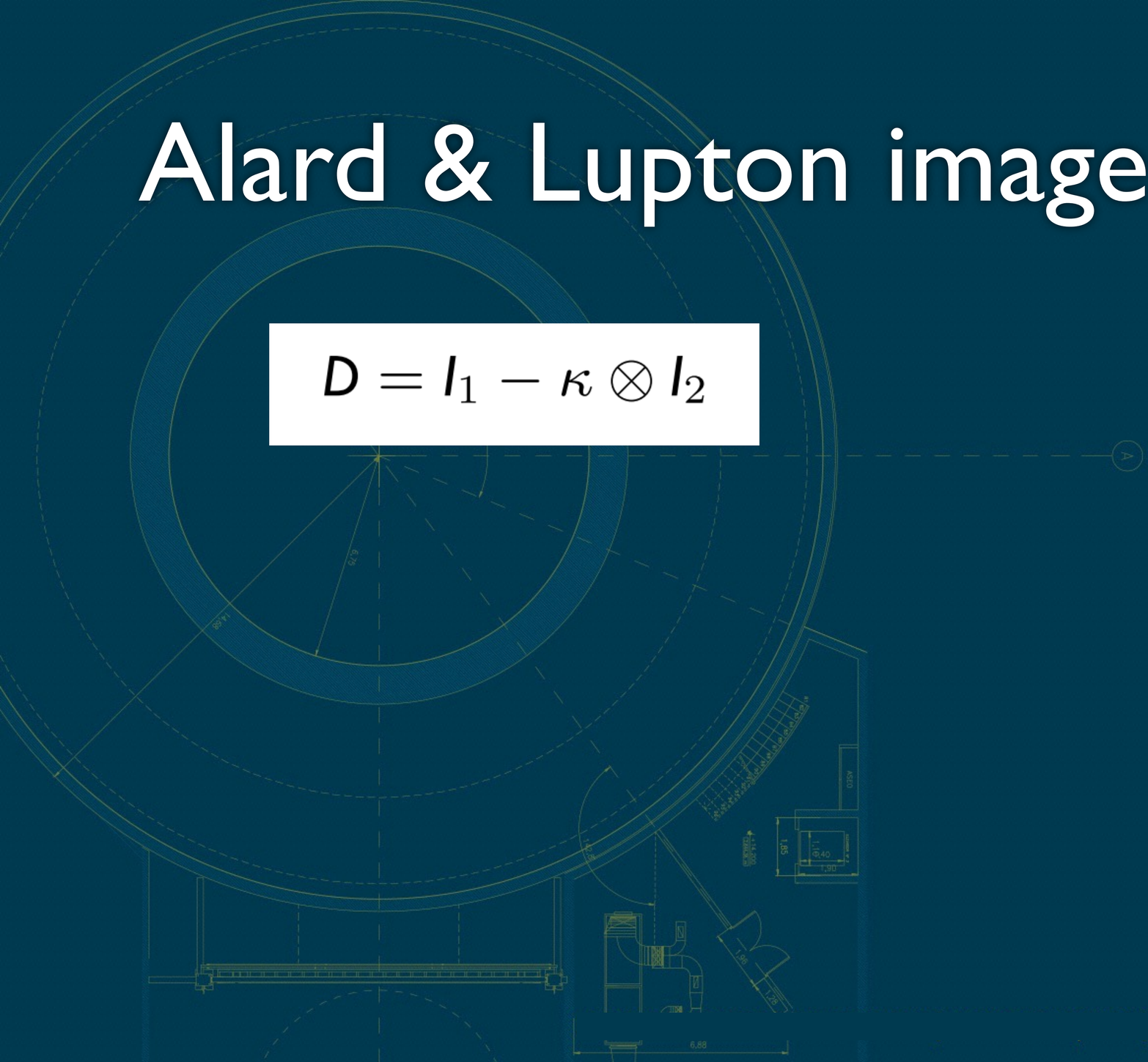
Francisco Forster (CMM) and Yusra AlSayyad (UW)



High Cadence Transient Survey DECam images subtracted with LSST Stack

Alard & Lupton image subtraction

$$D = I_1 - \kappa \otimes I_2$$



Alard & Lupton image subtraction

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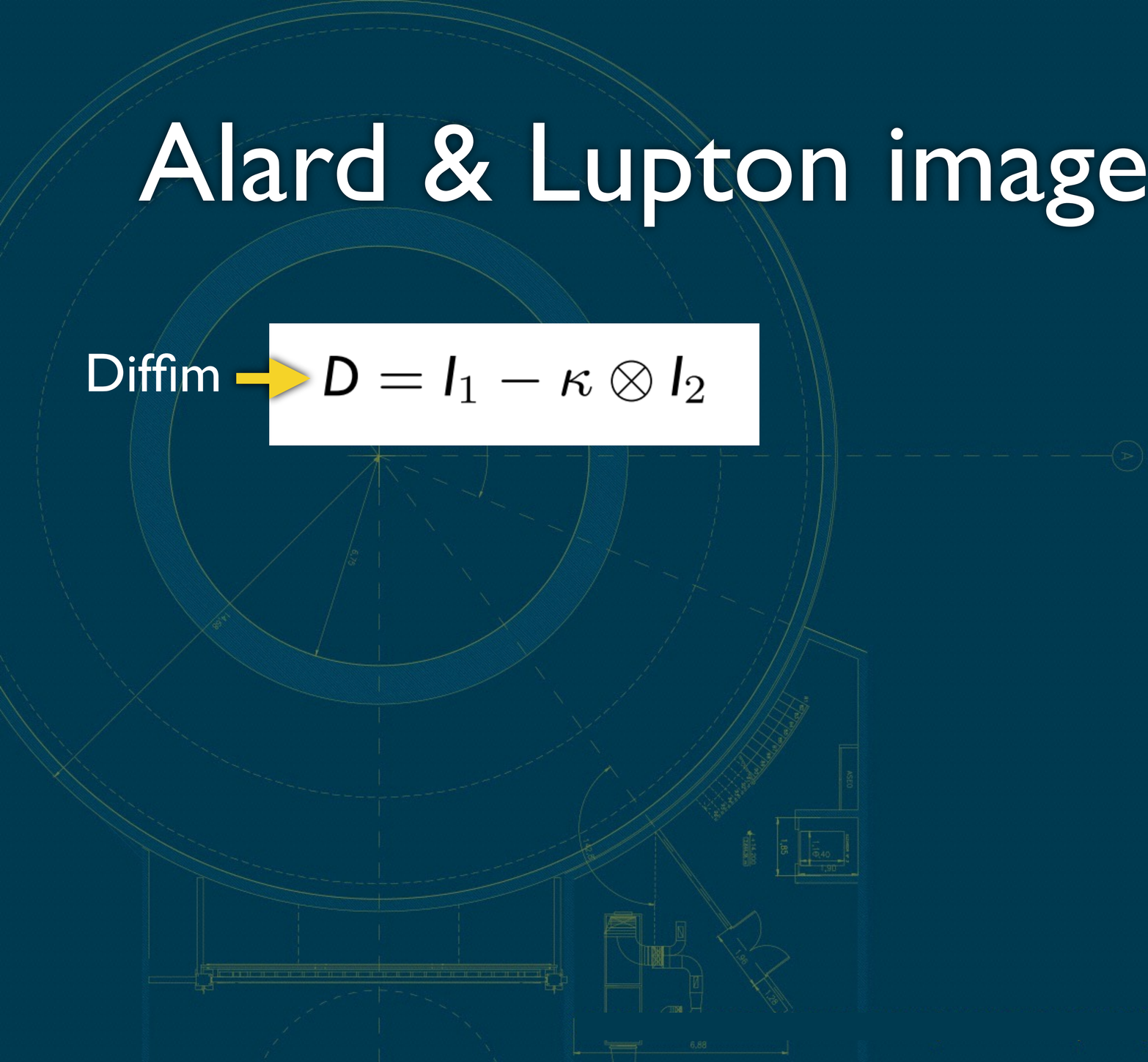

Alard & Lupton image subtraction

Diffim → $D = I_1 - \kappa \otimes I_2$

New

Template

Alard & Lupton image subtraction

Diffim

$$D = I_1 - \kappa \otimes I_2$$

New

PSF matching kernel

Template

Alard & Lupton image subtraction

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PSF matching kernel

Template

Expand k as:

$$\kappa = \sum_r a_r B^r$$

Alard & Lupton image subtraction

Diffim

$$D = I_1 - \kappa \otimes I_2$$

New

PSF matching kernel

Template

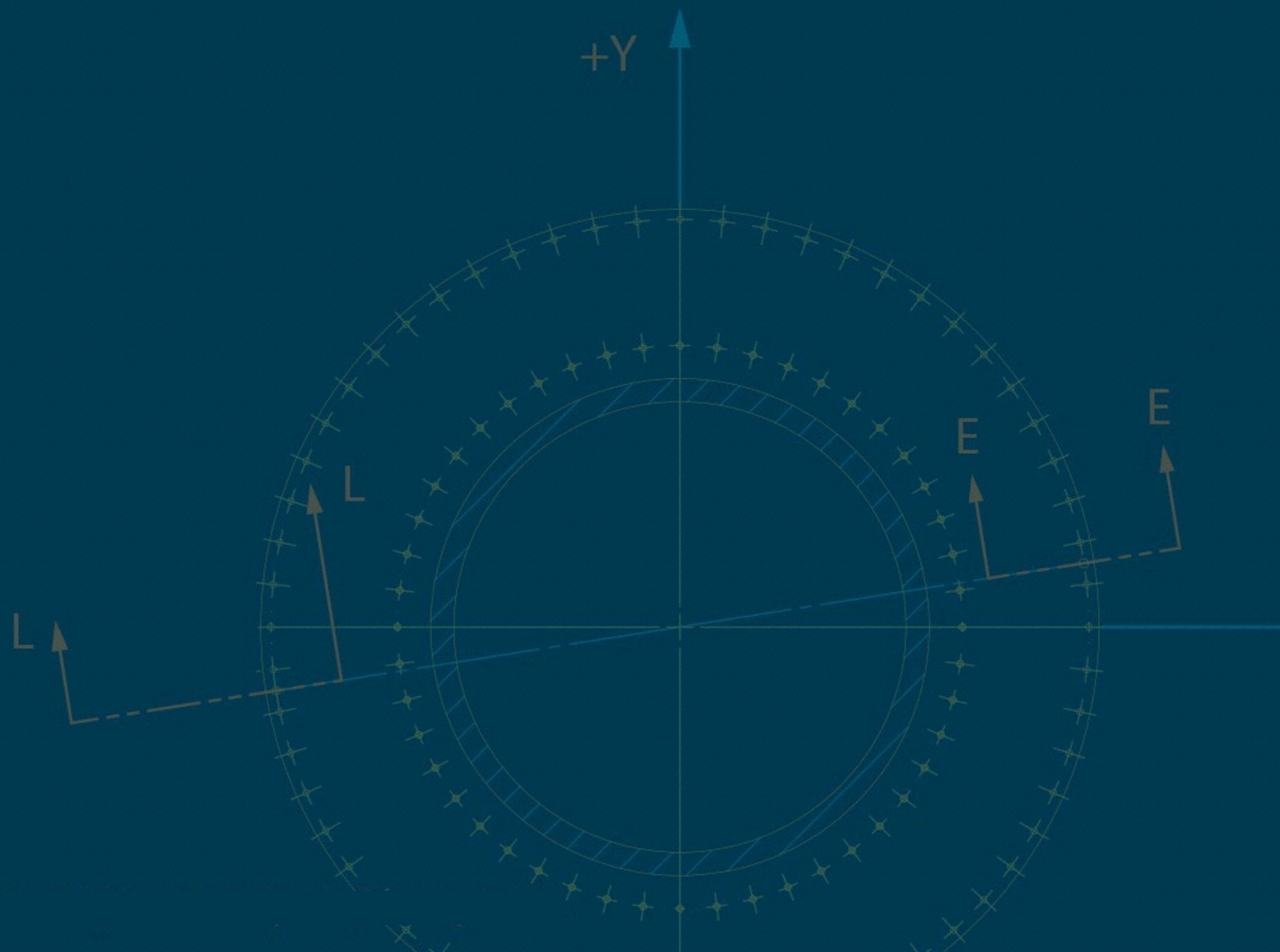
Expand k as:

$$\kappa = \sum_r a_r B^r$$

Minimize:

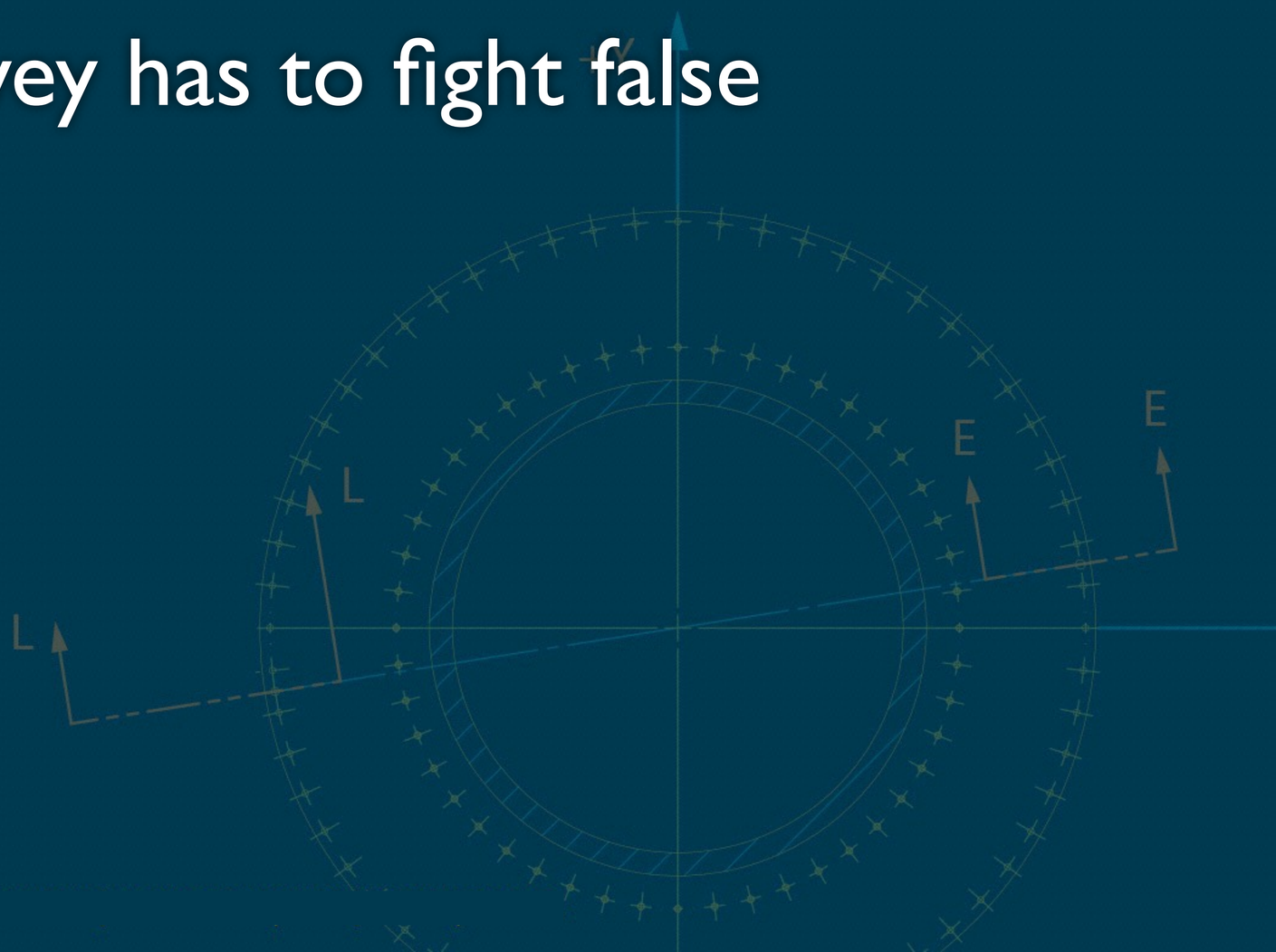
$$\left| \frac{I_1 - \sum_r a_r \left(B^r \otimes I_2 \right)}{\sigma} \right|^2$$

Understood issues with A&L



Understood issues with A&L

- Every transient survey has to fight false positives



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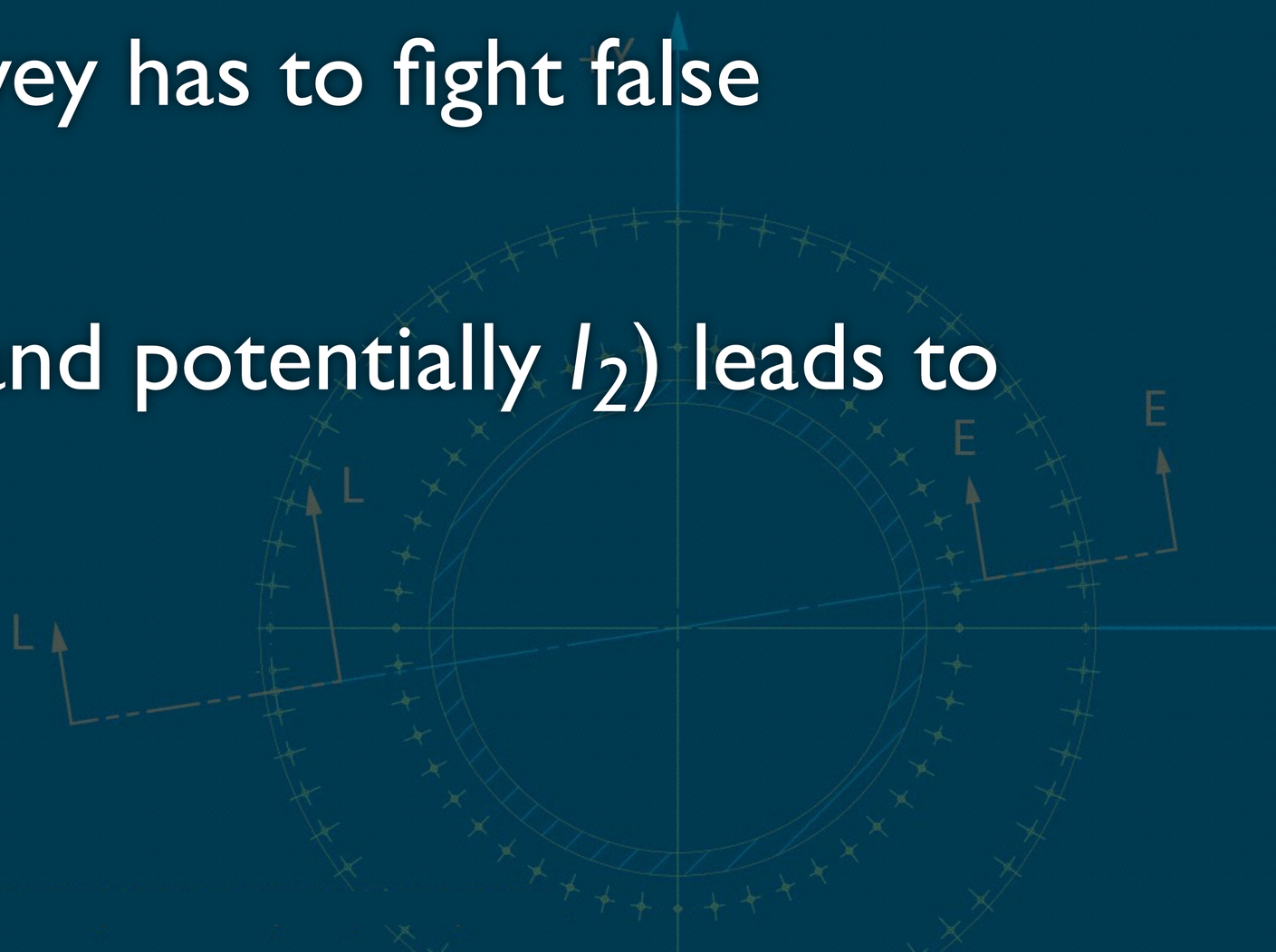
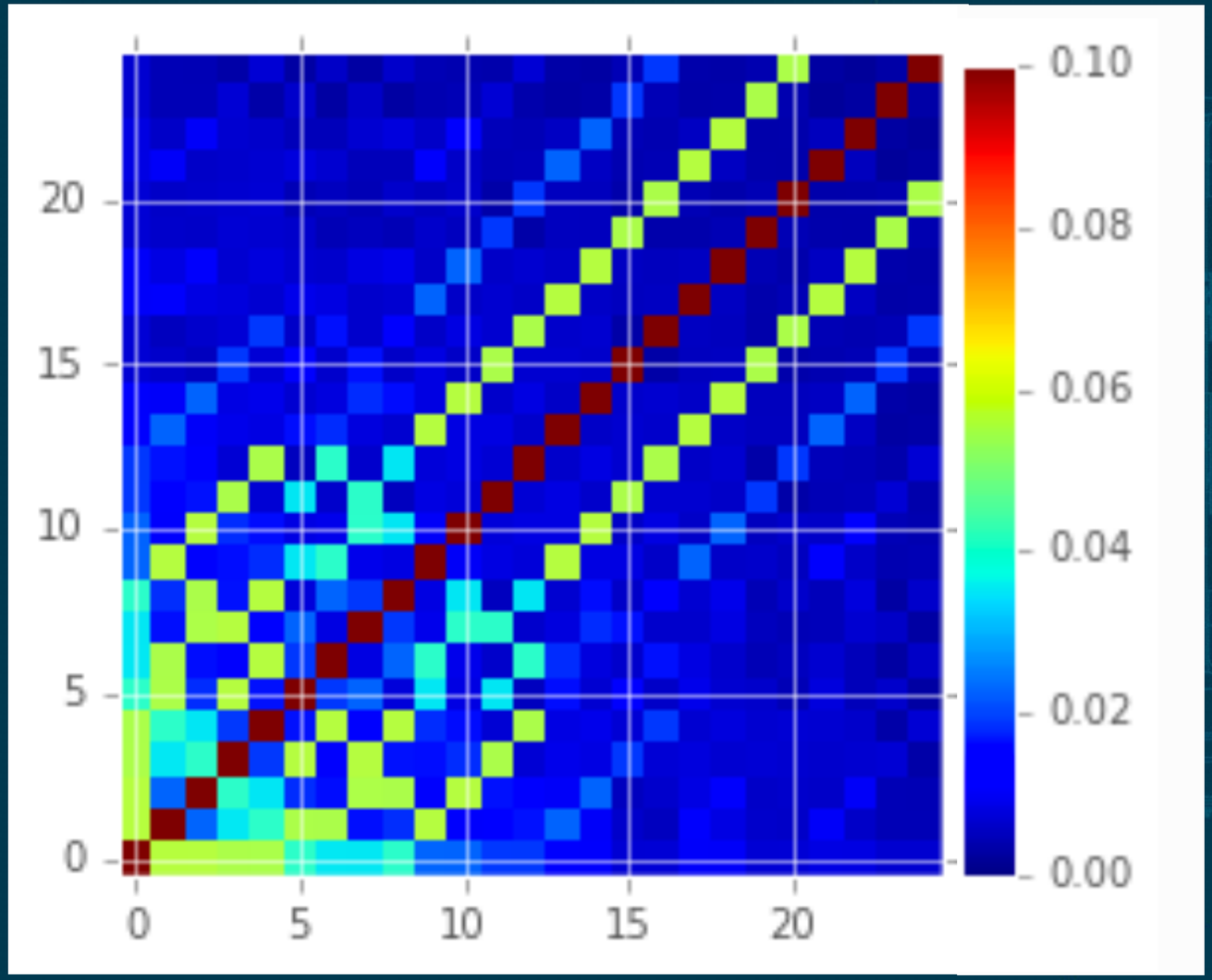
- Convolution of I_1 (and potentially I_2) leads to correlated noise



Understood issues with A&L

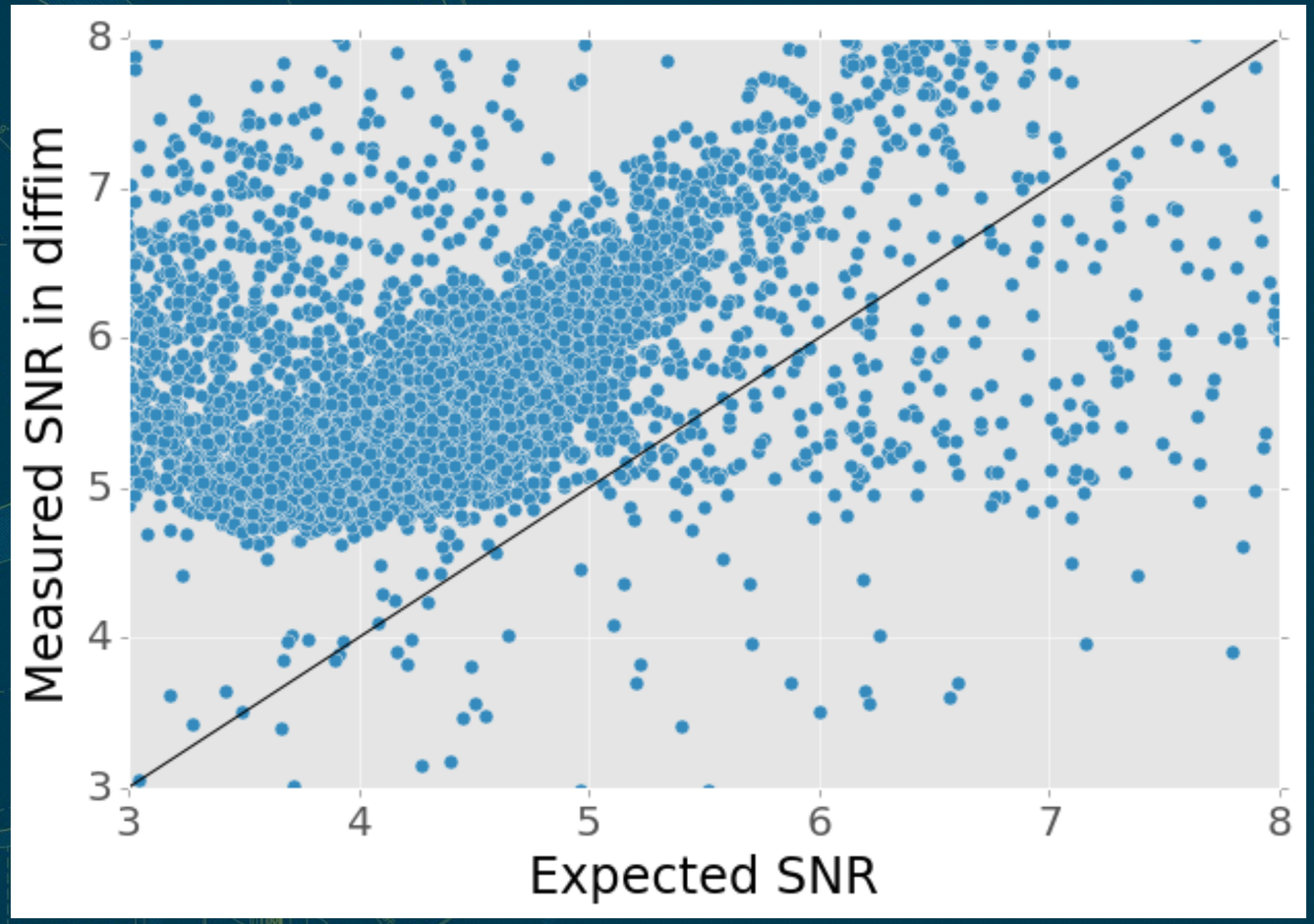
- Every transient survey has to fight false positives
- Convolution of I_1 (and potentially I_2) leads to correlated noise
- Correlated noise leads to underestimated noise in the subtracted image

Effect of PSF matching: High neighboring pixel covariance



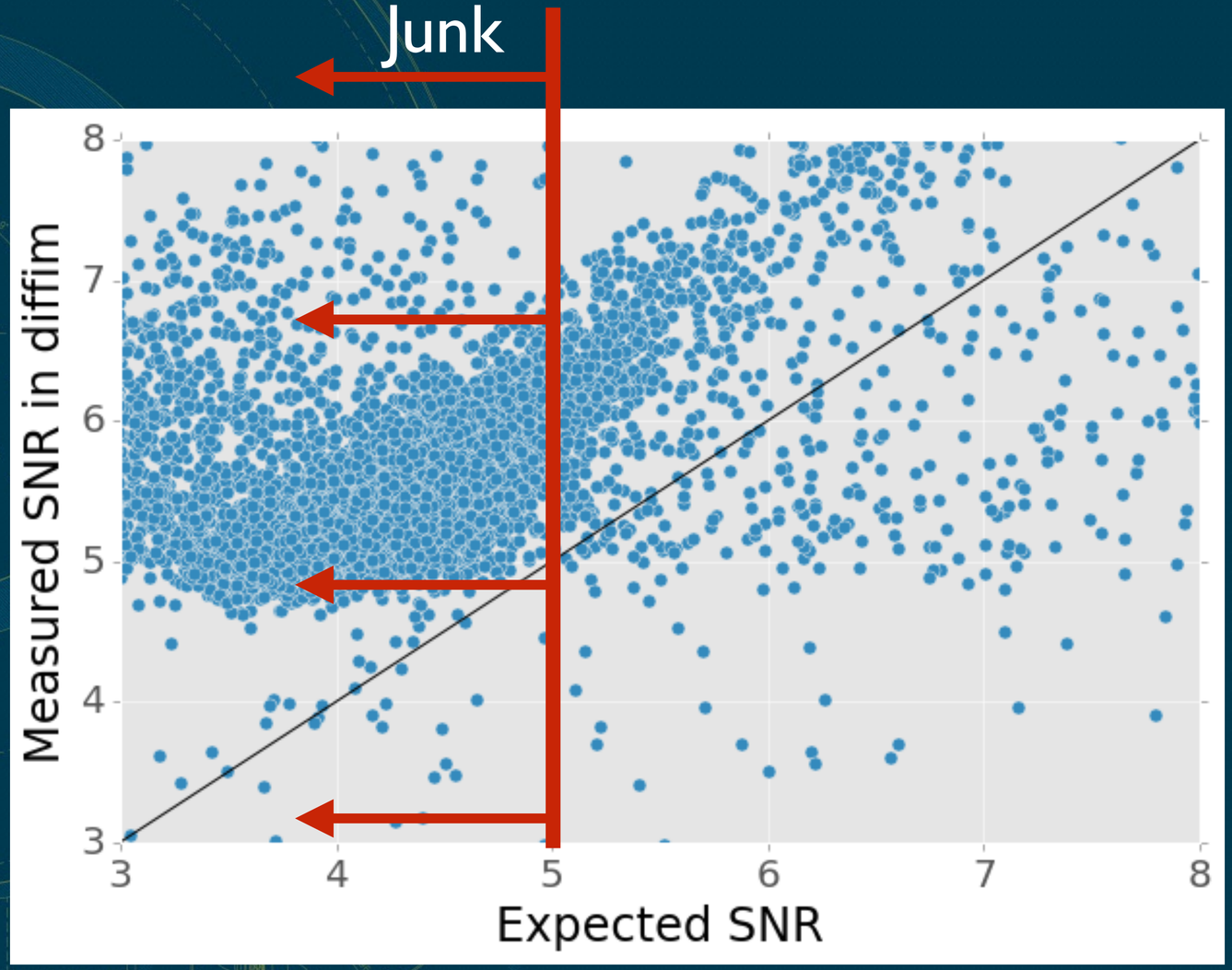
~30% of covariance is off-diagonal

Effect of correlated noise



http://dmtn-006.lsst.io http://dmtn-021.lsst.io

Effect of correlated noise

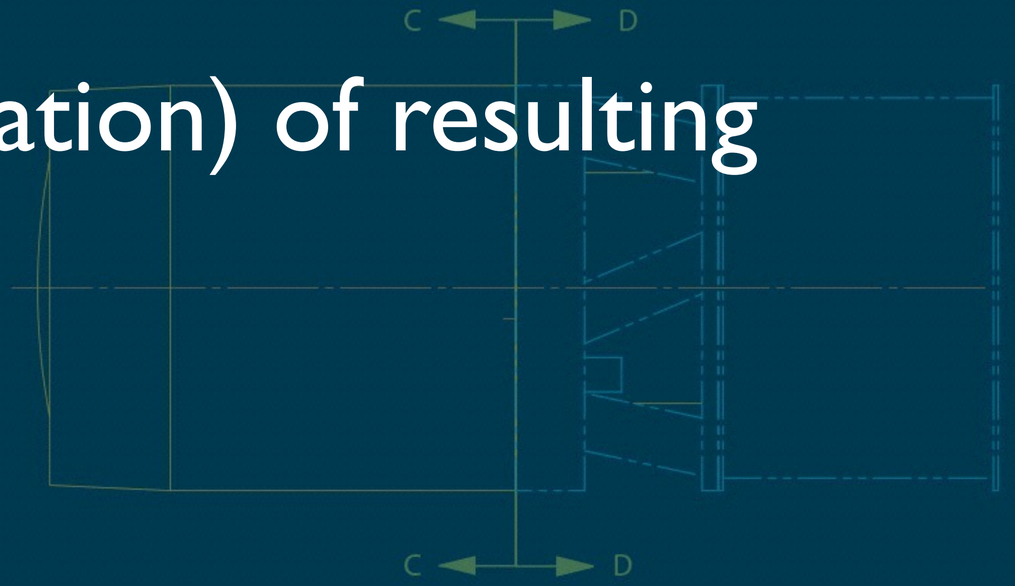


http://dmtn-006.lsst.io http://dmtn-021.lsst.io

Proper image subtraction

Zackay, Ofek, and Gal-Yam (2015) — "ZOGY"

- *Cross-correlation* of each image with the other's PSF
- *Noise whitening* (decorrelation) of resulting diffim



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The A&L/ZOGY "Afterburner"

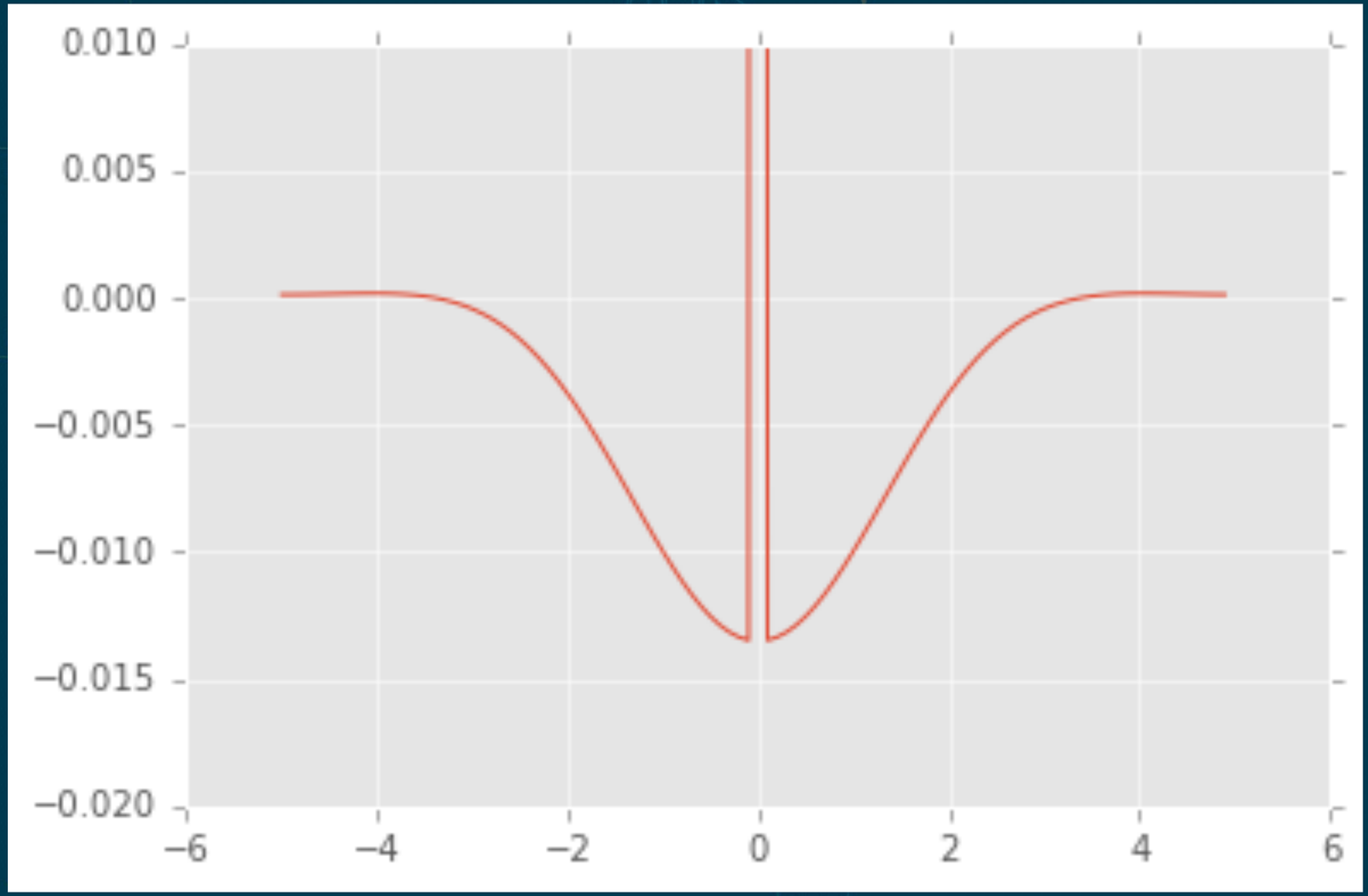
- Noise whitening can be performed on an A&L image difference too.

$$\hat{D}(k) = (I_1(k) - \kappa(k) I_2(k)) \sqrt{\frac{\sigma_1^2 + \sigma_2^2}{\sigma_1^2 + \kappa^2(k)\sigma_2^2}}$$

http://dmtn-021.lsst.io

Decorrelating the A&L diffim

$$\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{\sigma_1^2 + \kappa^2(k)\sigma_2^2}}$$



Decorrelating the A&L diffim

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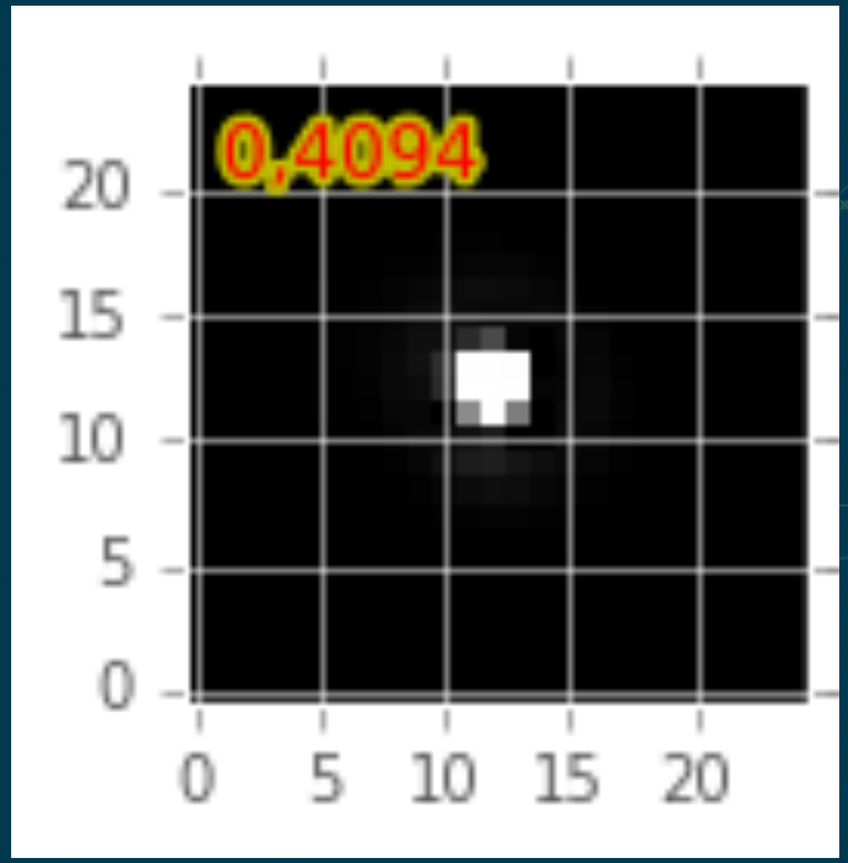

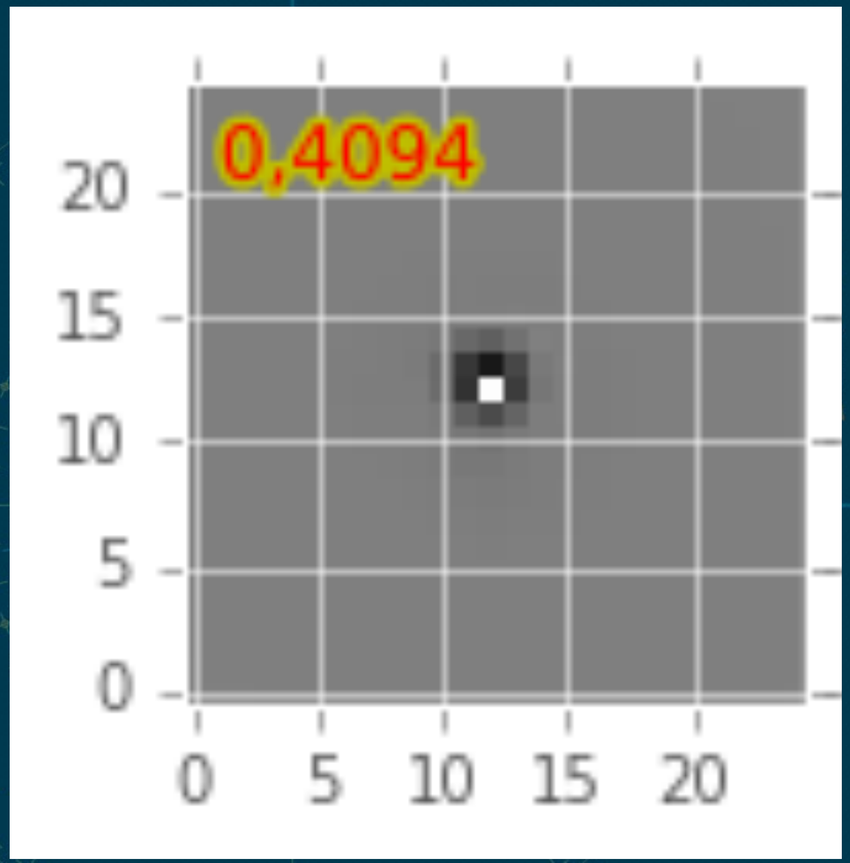

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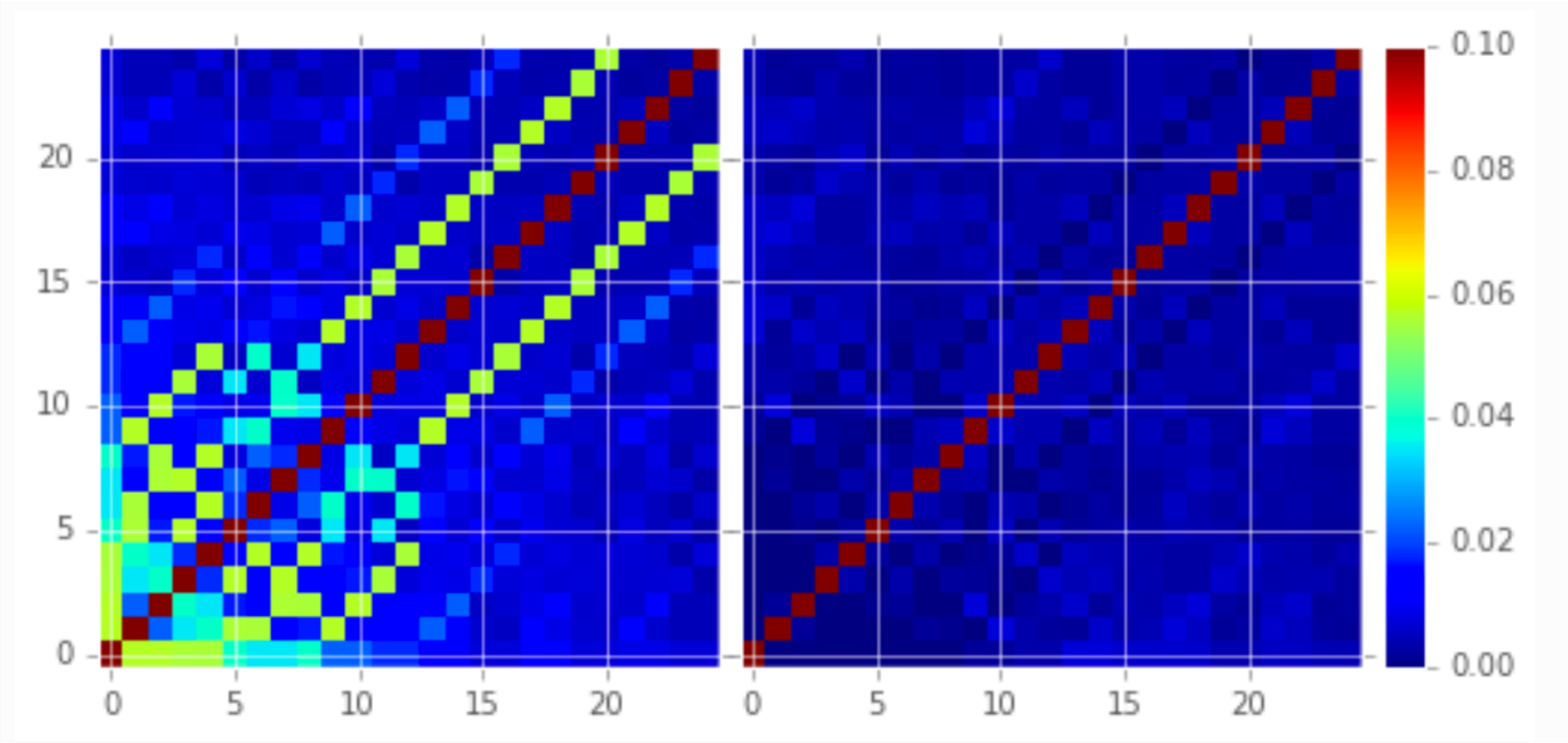
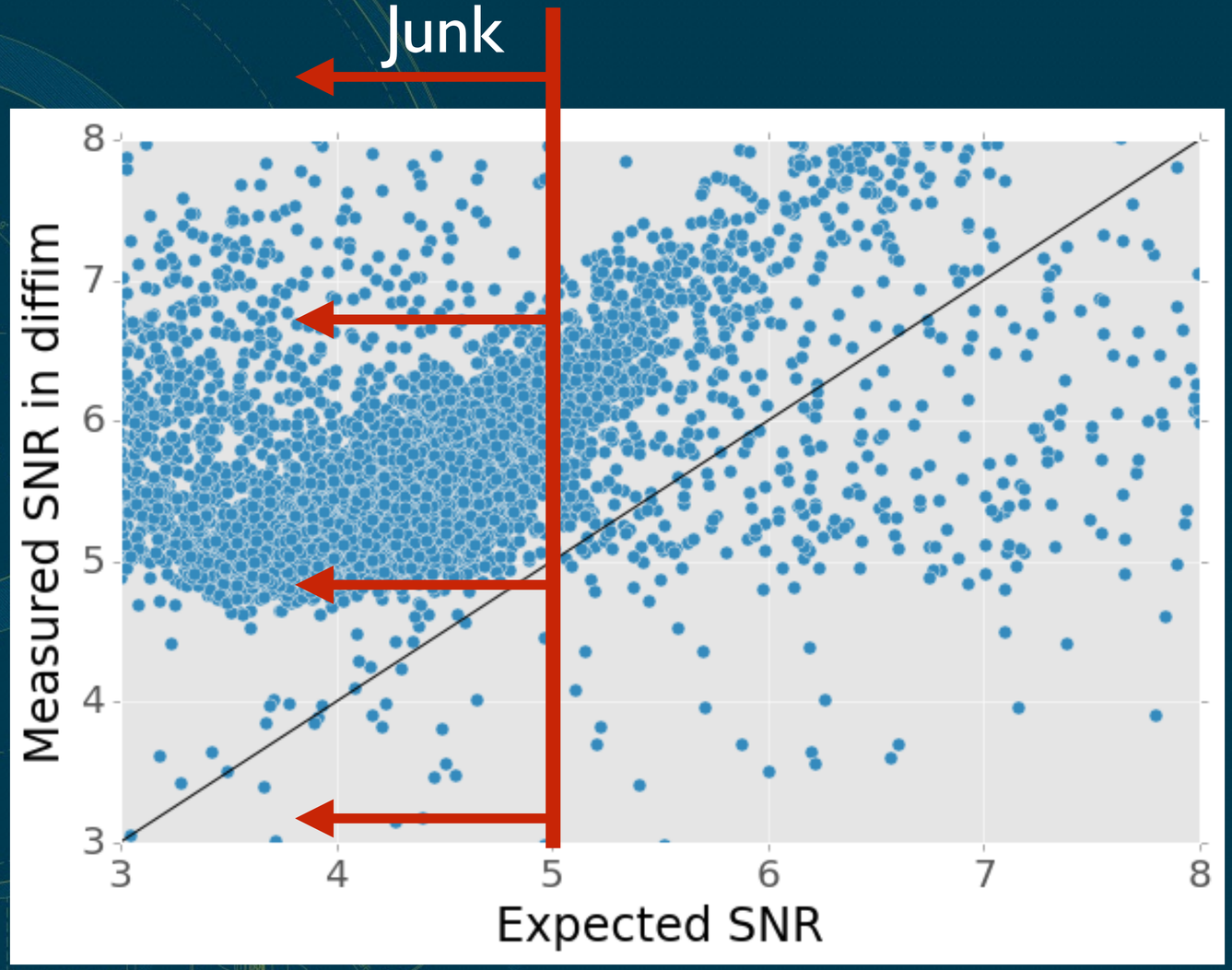


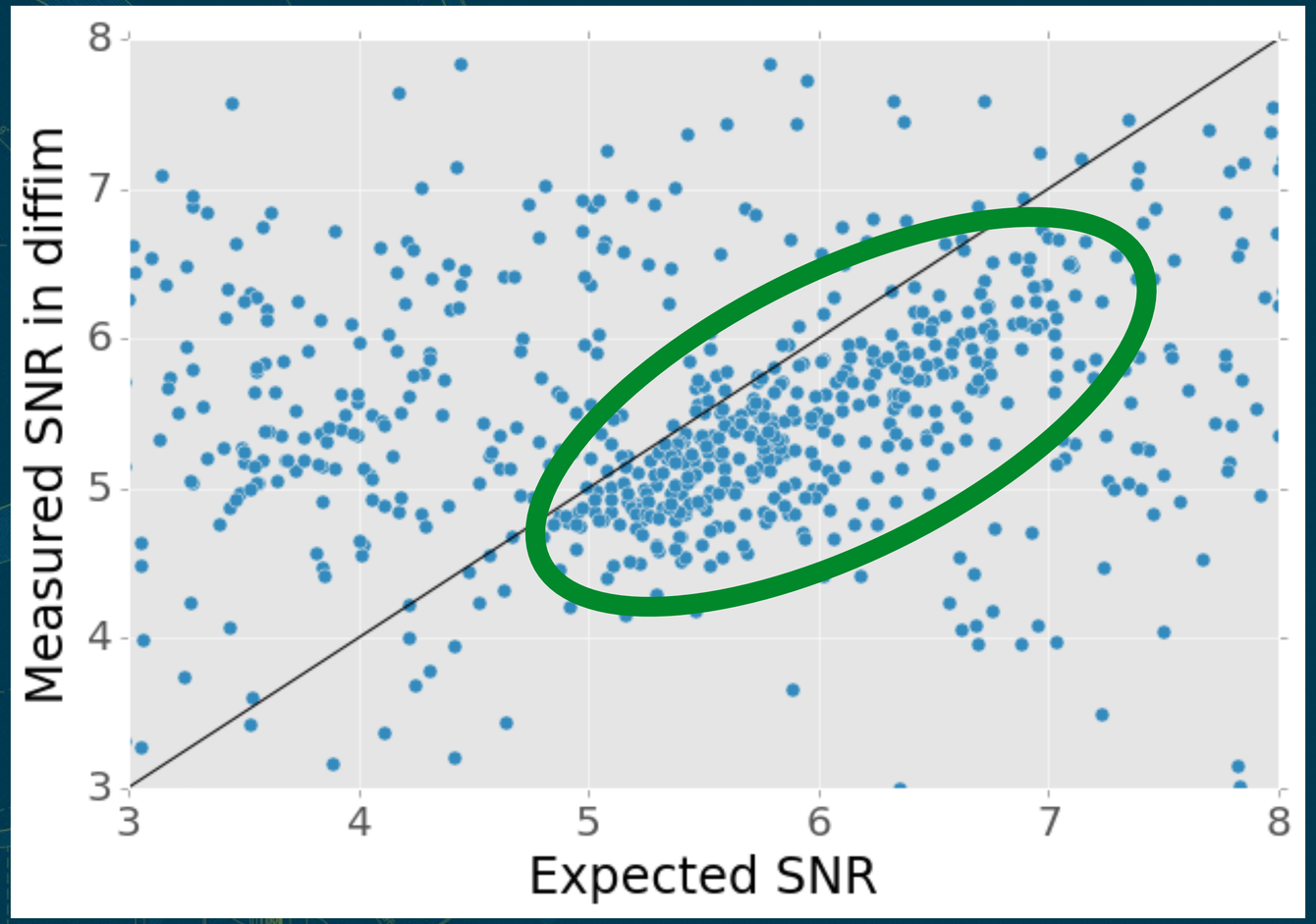
Neighboring pixel covariances

Without Decorrelation



http://dmtn-021.lsst.io

With Decorrelation

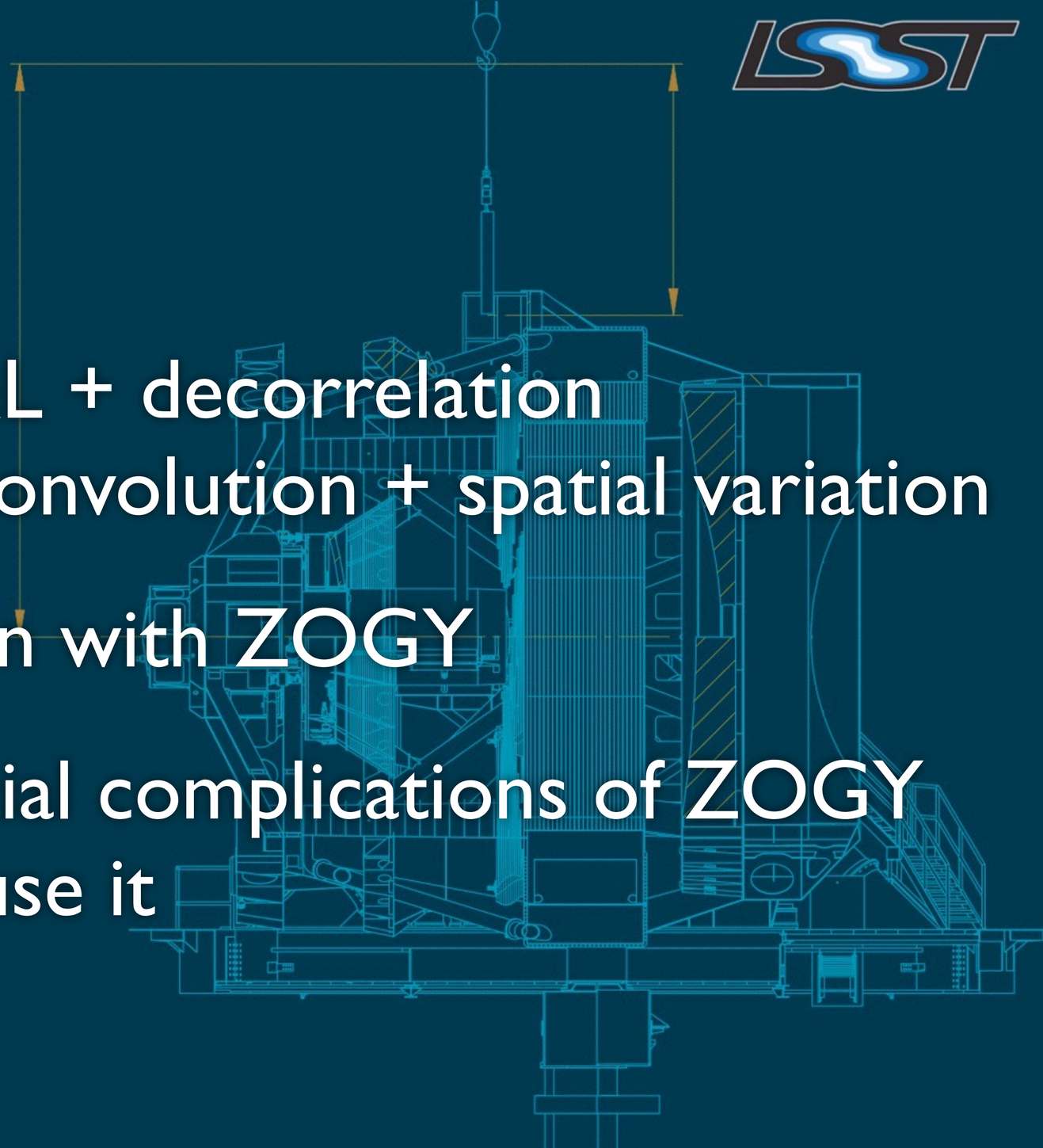


Real detections
at the right SNR

http://dmtn-021.lsst.io

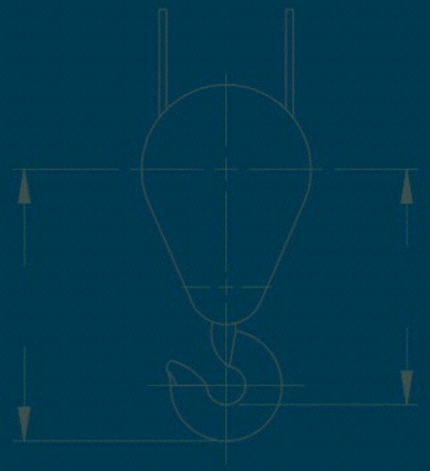
- Decorrelation reduces false detection rate from ~20k/sq deg to <1000/sq deg
- Much closer to the expected rate of astrophysical transients
- With cuts for finding Solar System objects, puts us in the ~few hundred/sq deg range.

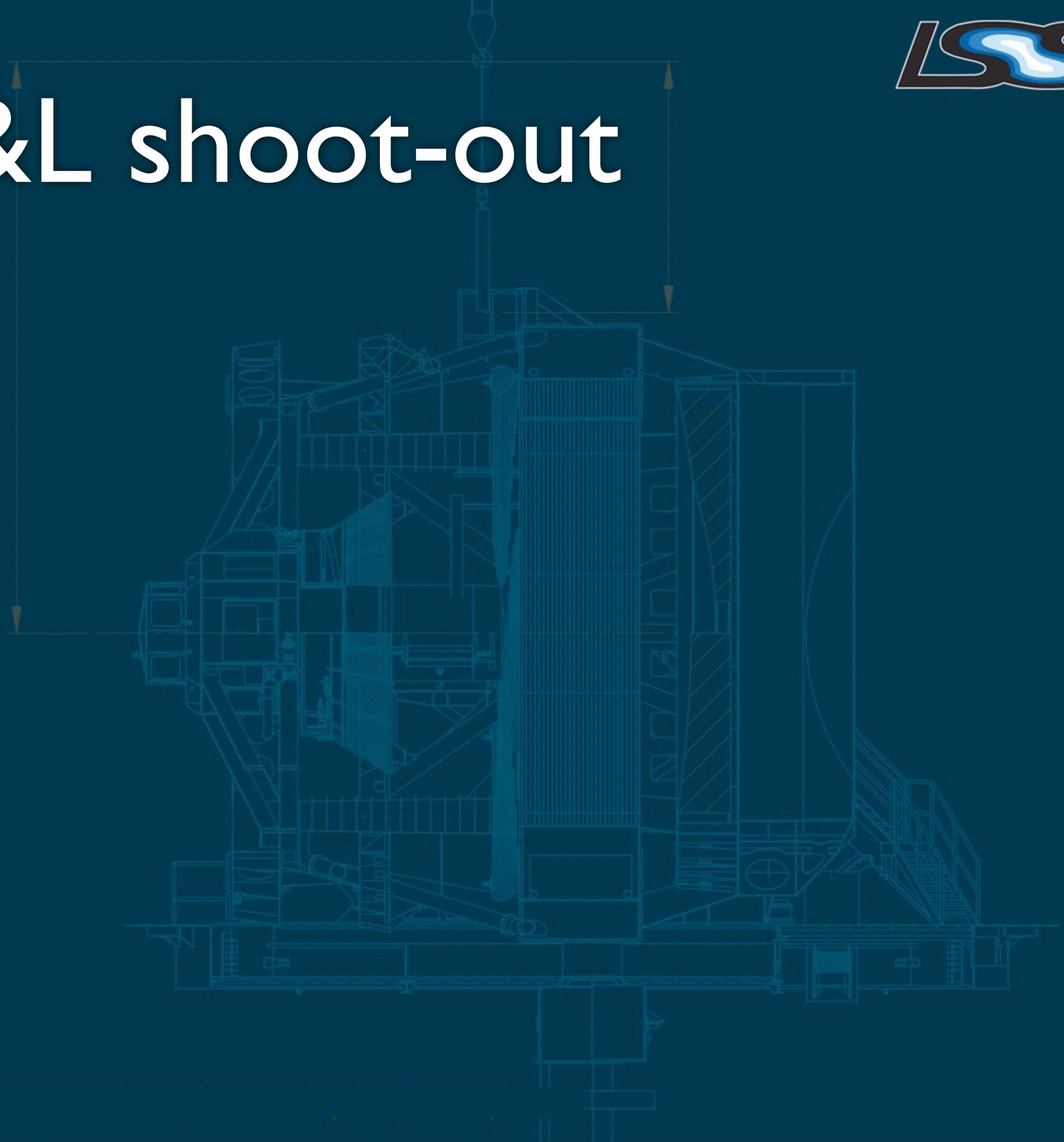
Ongoing work



- Implementation of A&L + decorrelation "afterburner" + pre-convolution + spatial variation
- Systematic comparison with ZOGY
- Understanding potential complications of ZOGY and whether we can use it

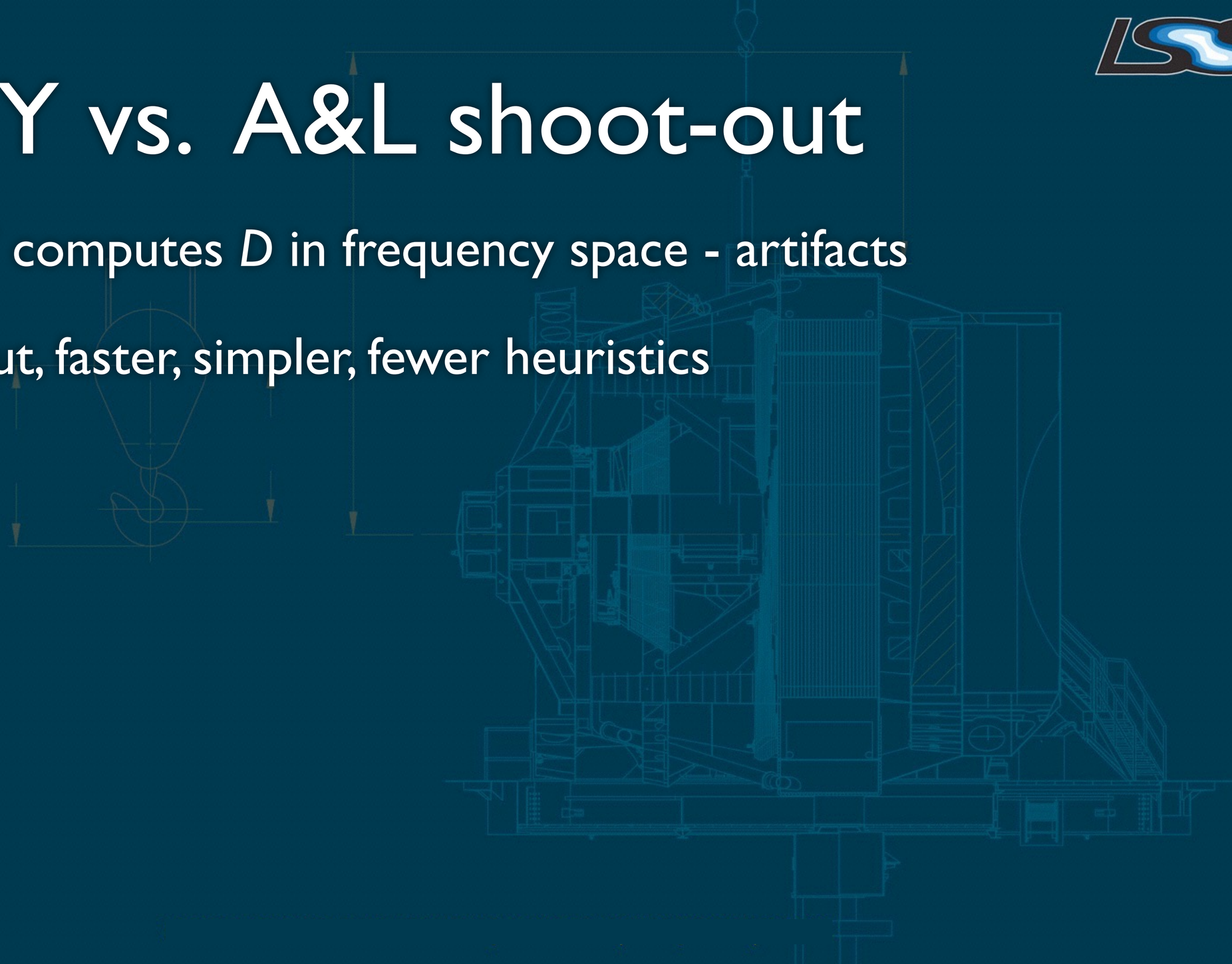
ZOGY vs. A&L shoot-out





ZOGY vs. A&L shoot-out

- ZOGY computes *D* in frequency space - artifacts
  - …but, faster, simpler, fewer heuristics



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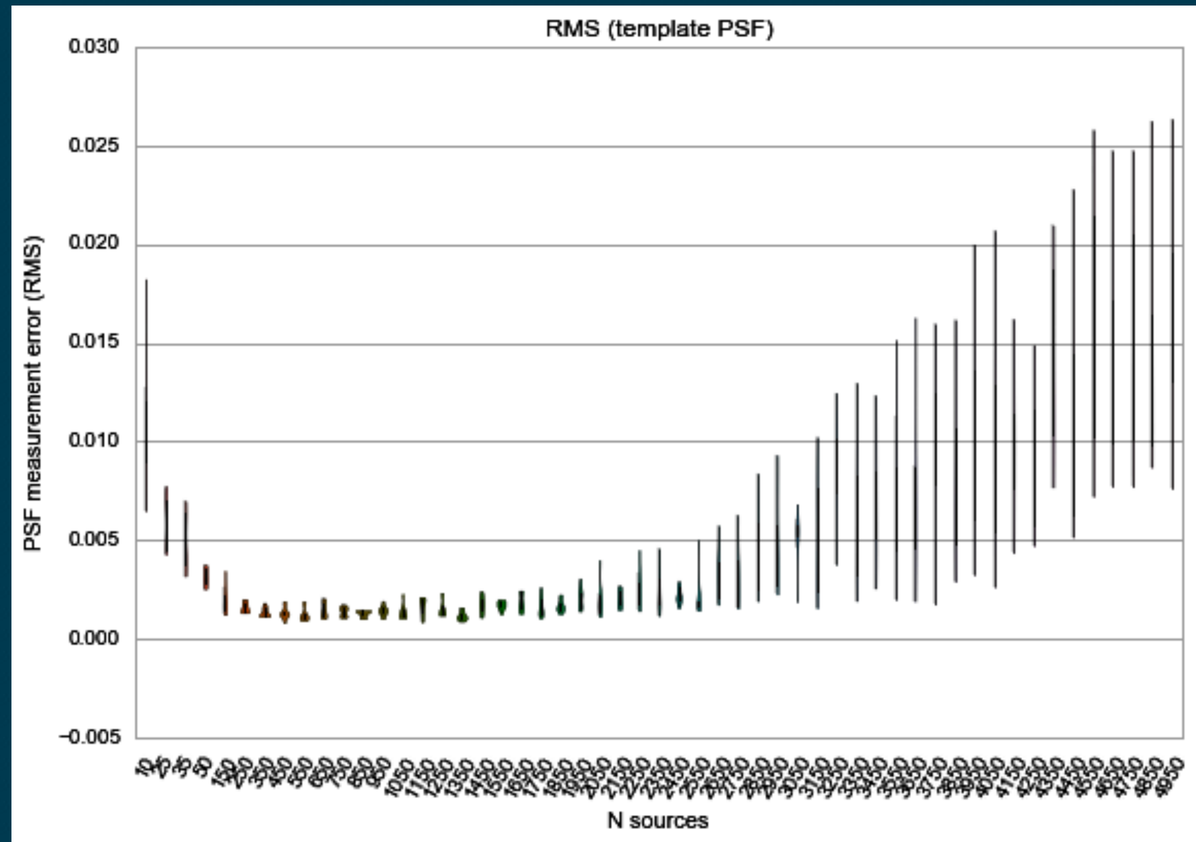
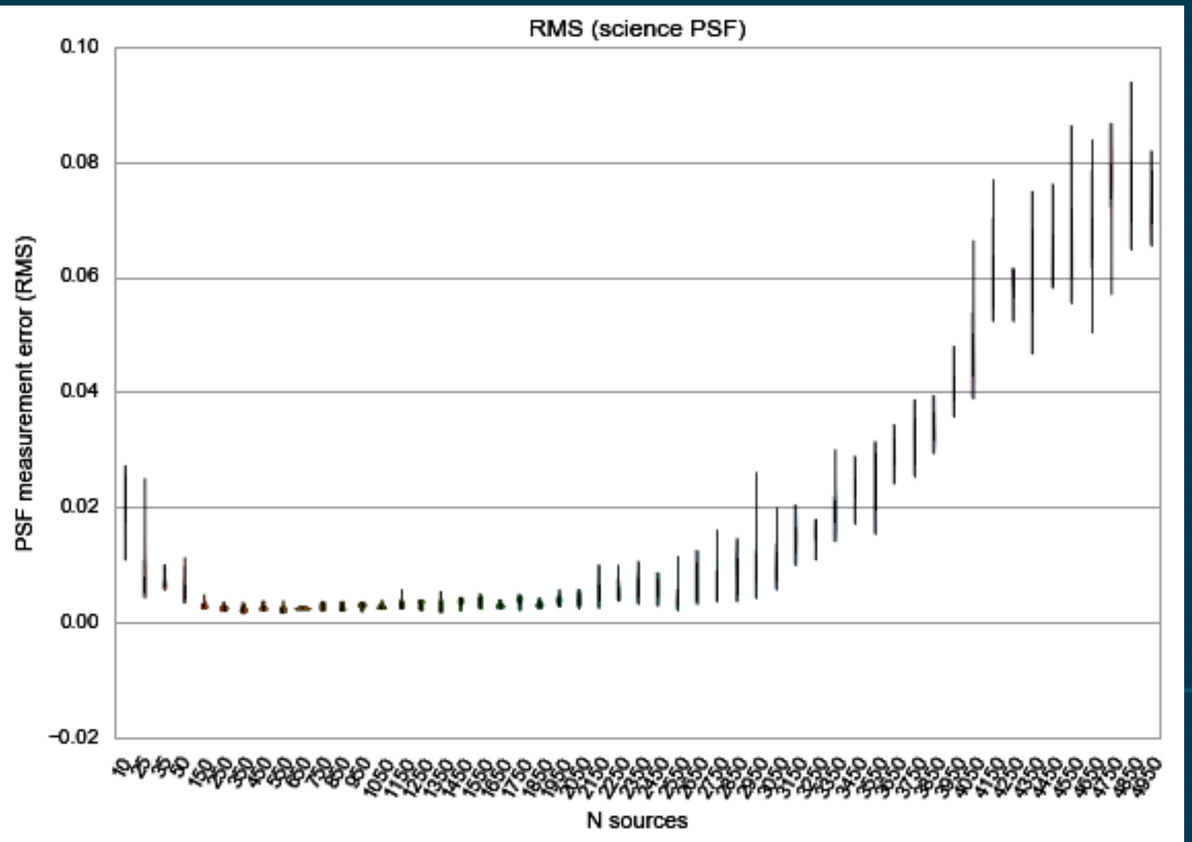
- ZOGY is symmetric. A&L is not. A&L has issues if PSFs are nearly identical. Pre-convolution for A&L is a bit "hacky".
- ZOGY requires accurate measurement of PSFs of both images. A&L does not. **This might be an issue.**

PSF Measurement in LSST Stack

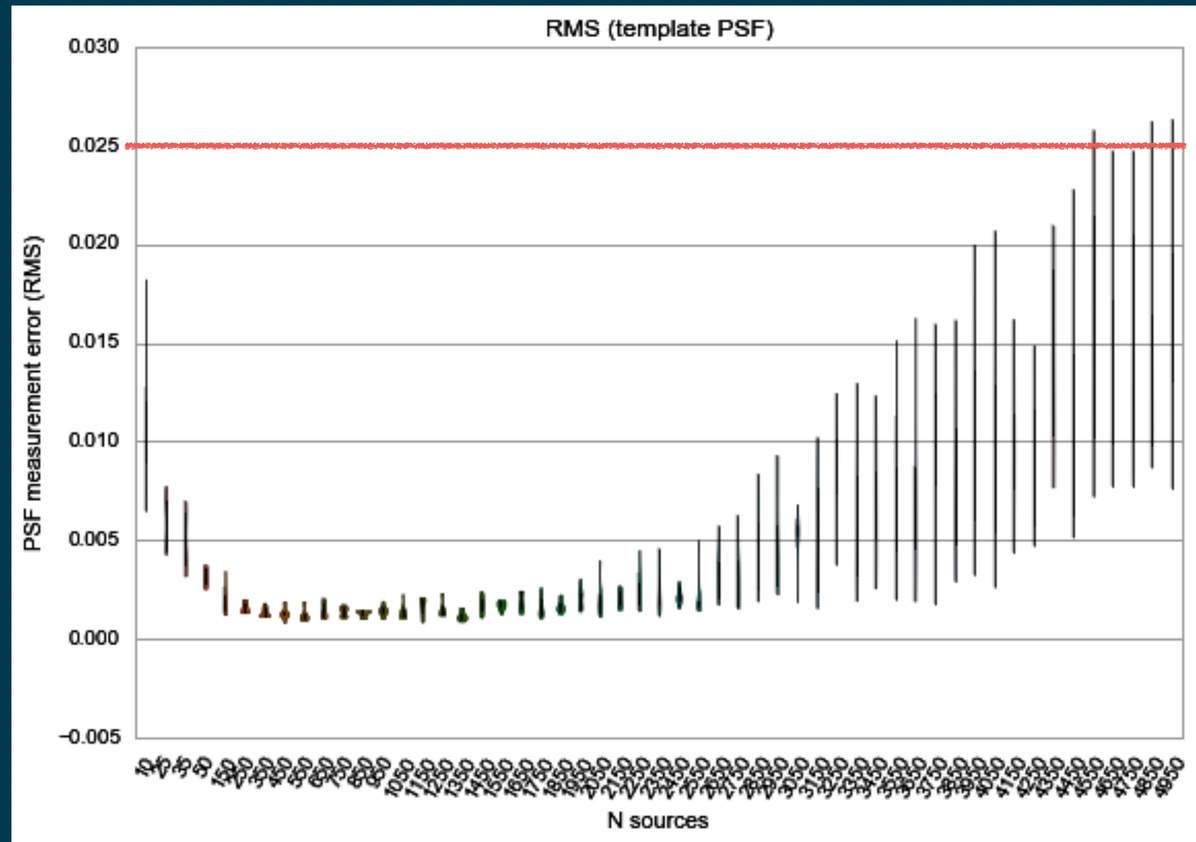


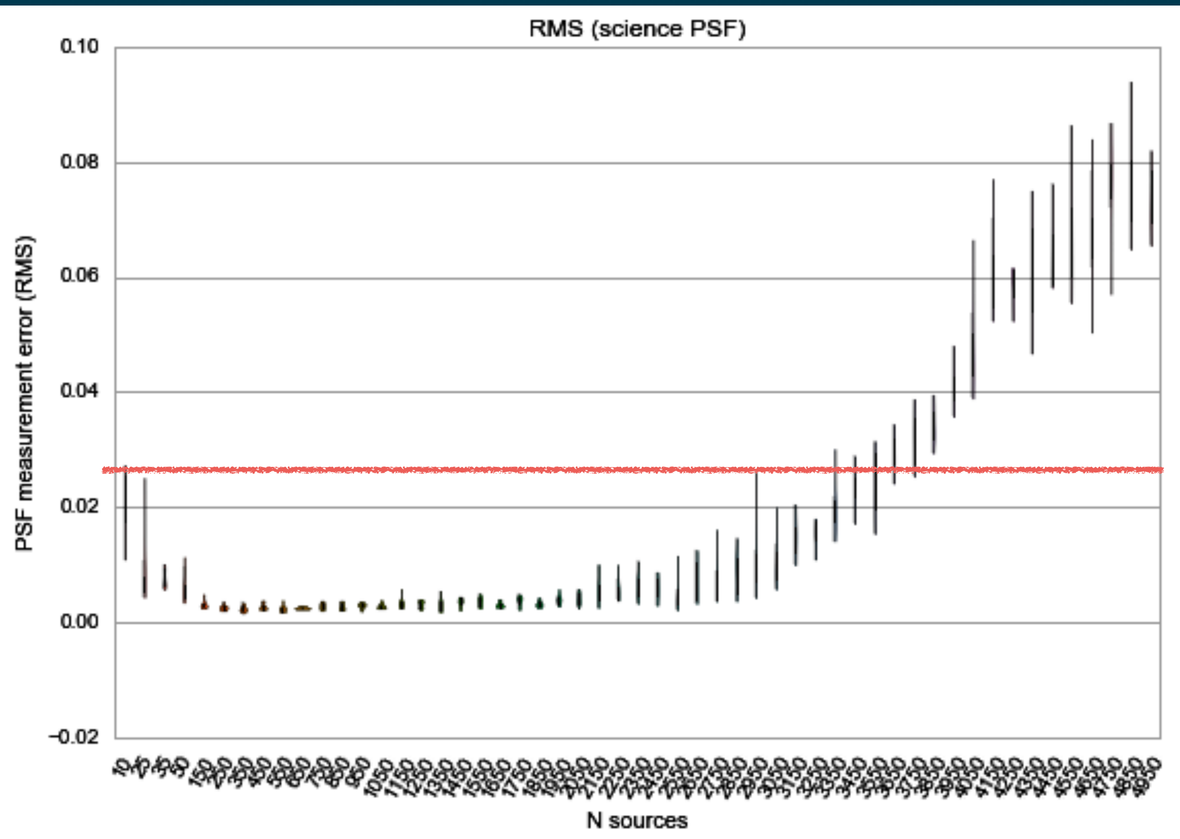


Template: 0.75” FWHM

Science: 1.04” FWHM

PSF Measurement in LSST Stack





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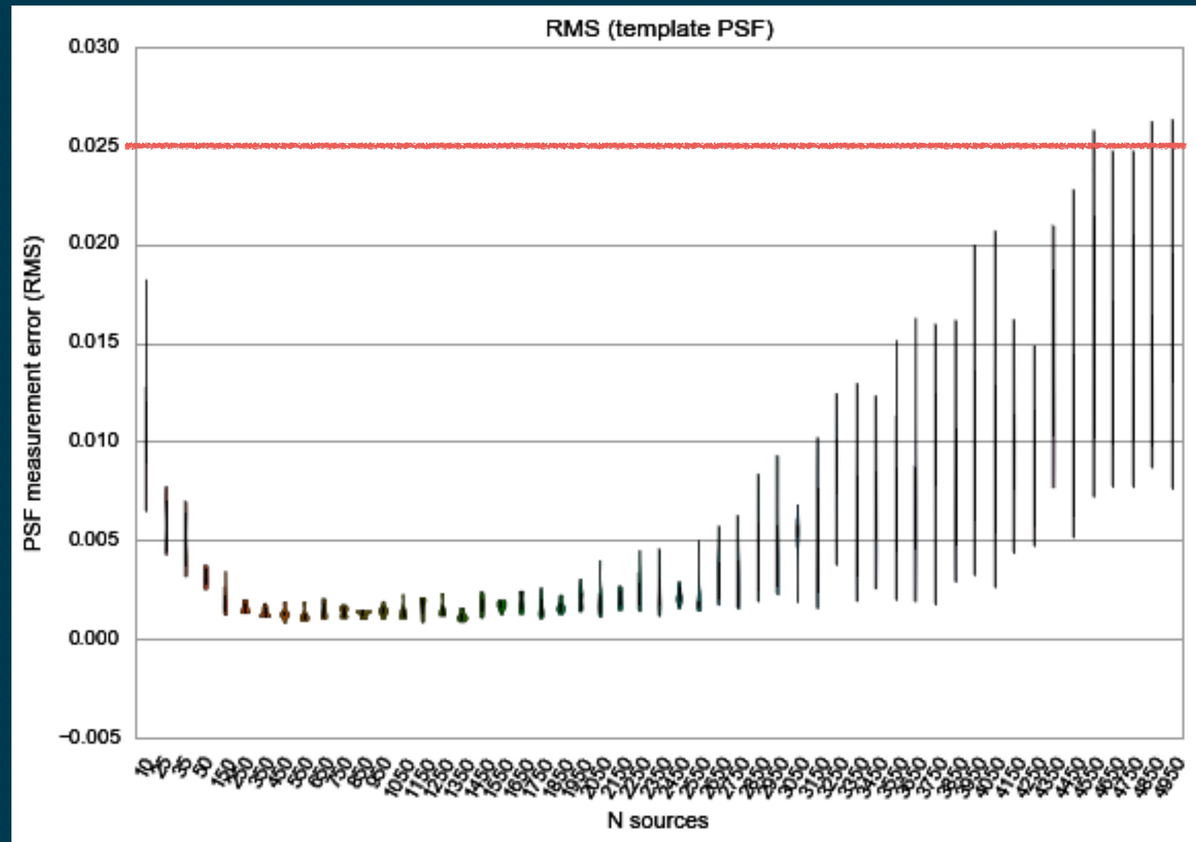

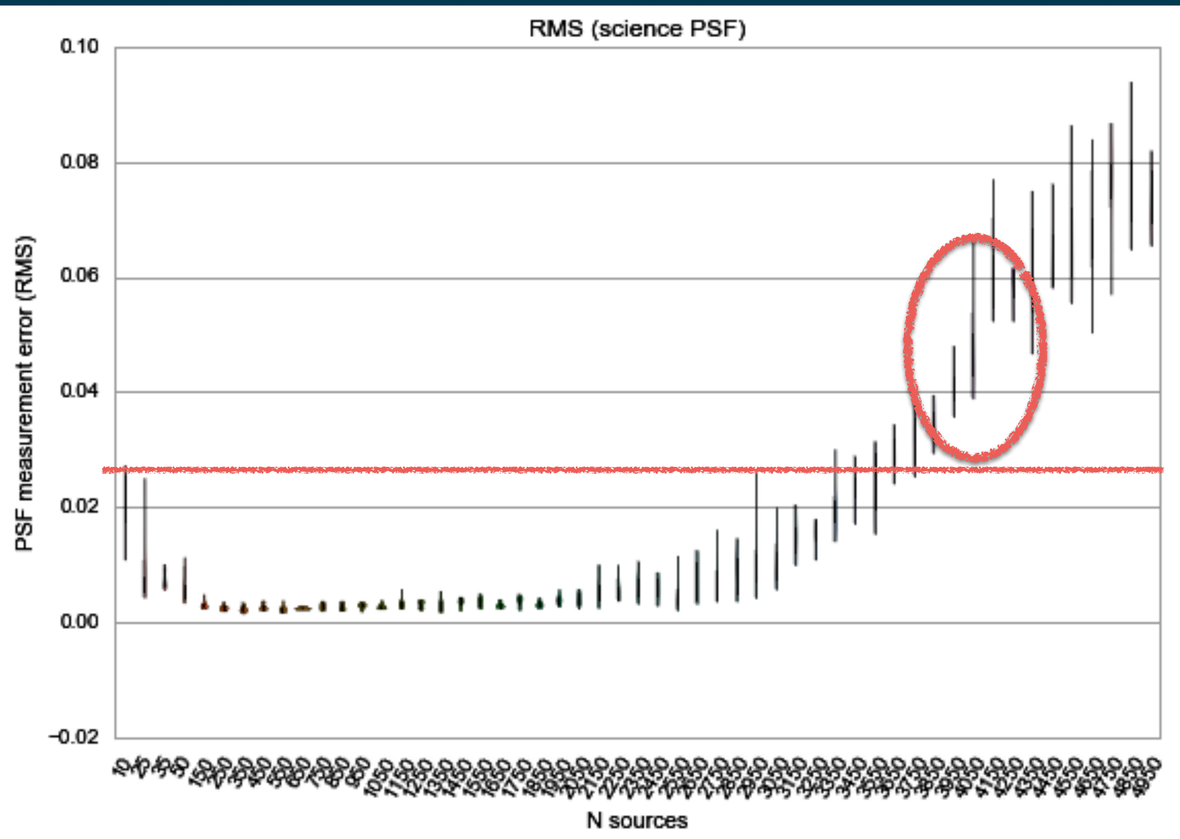

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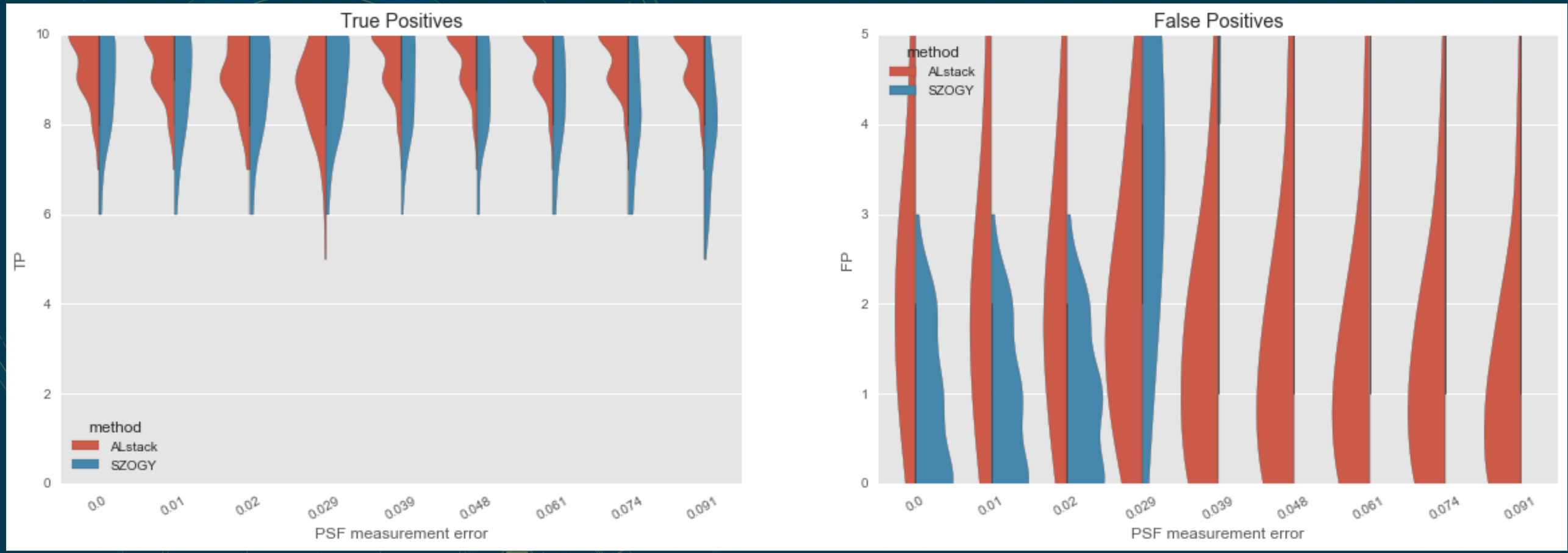
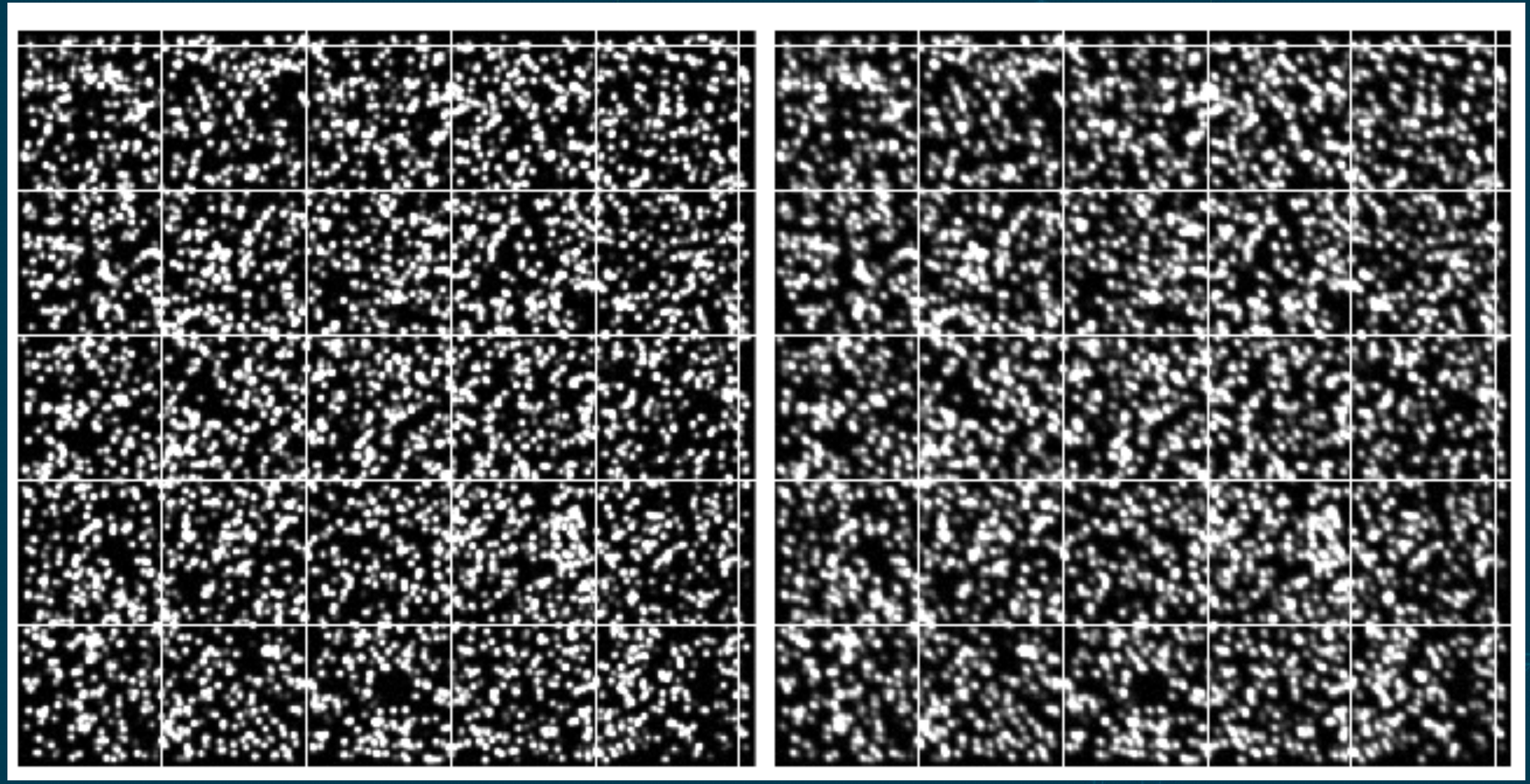
How can we “break” ZOGY?



Detection rate as a function of PSF mis-estimation

PSF Measurement in LSST Stack



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Science: 1.04” FWHM

Summary

- We have recently improved the 20-year old A&L optimal image subtraction algorithm
  - Reduced rate of false positive detections by ~90% *with no machine learning*.
- We have implemented and are currently and testing the Zackay, et al. (2015) proper image subtraction algorithm.