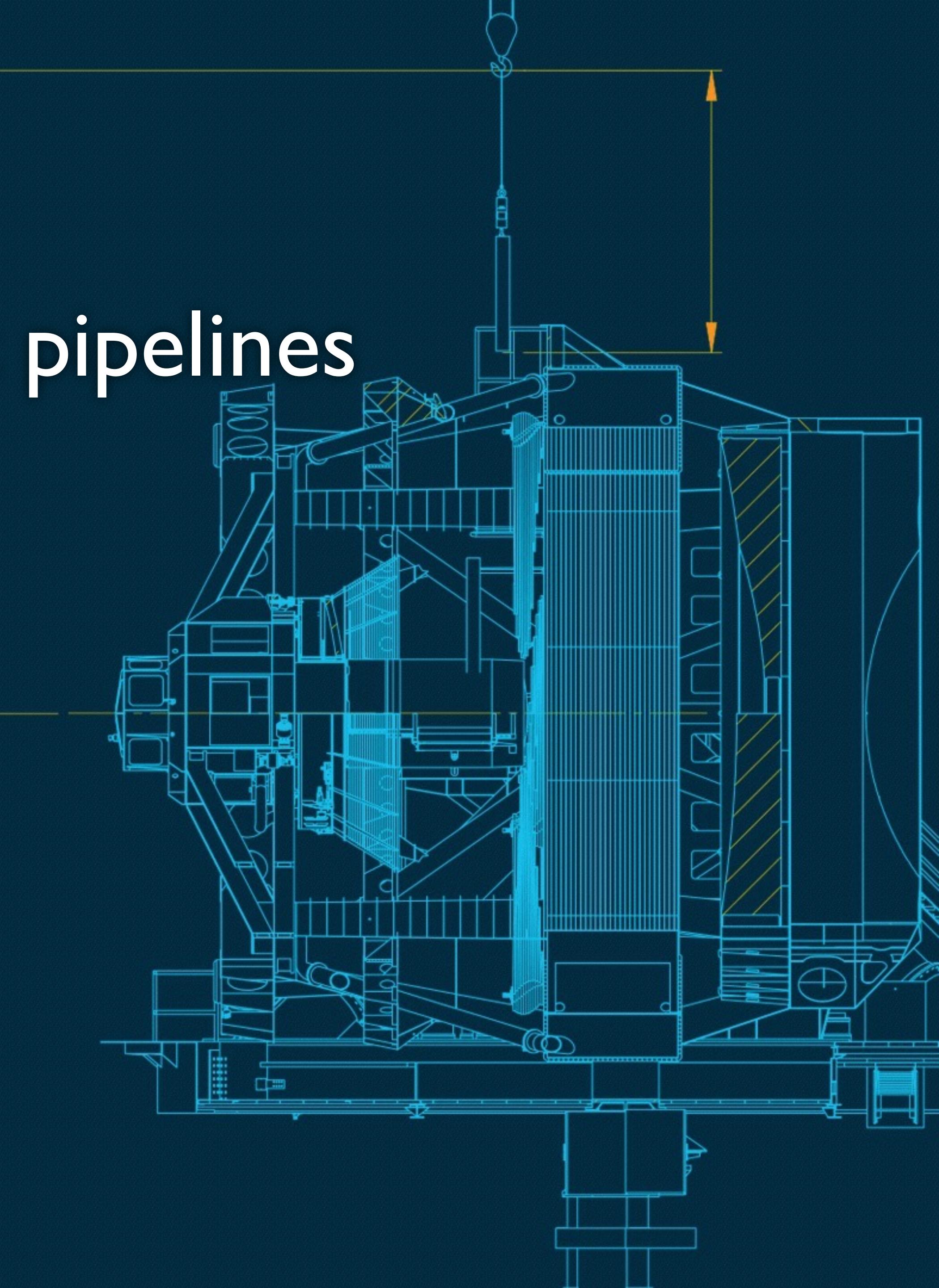


Image differencing

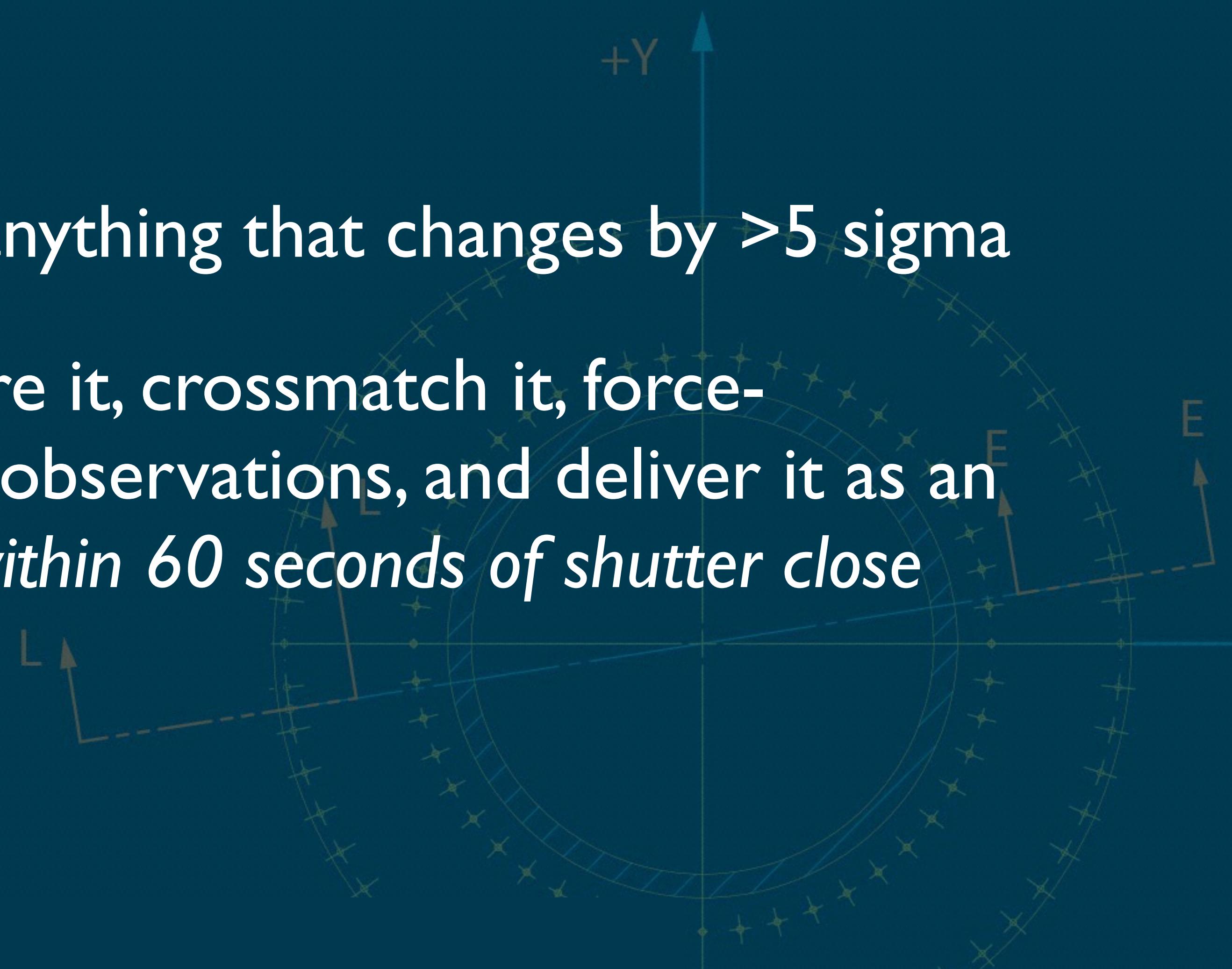
Status and plans for LSST alert pipelines

David Reiss
LSST DM Research Scientist
University of Washington



Level I: 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*

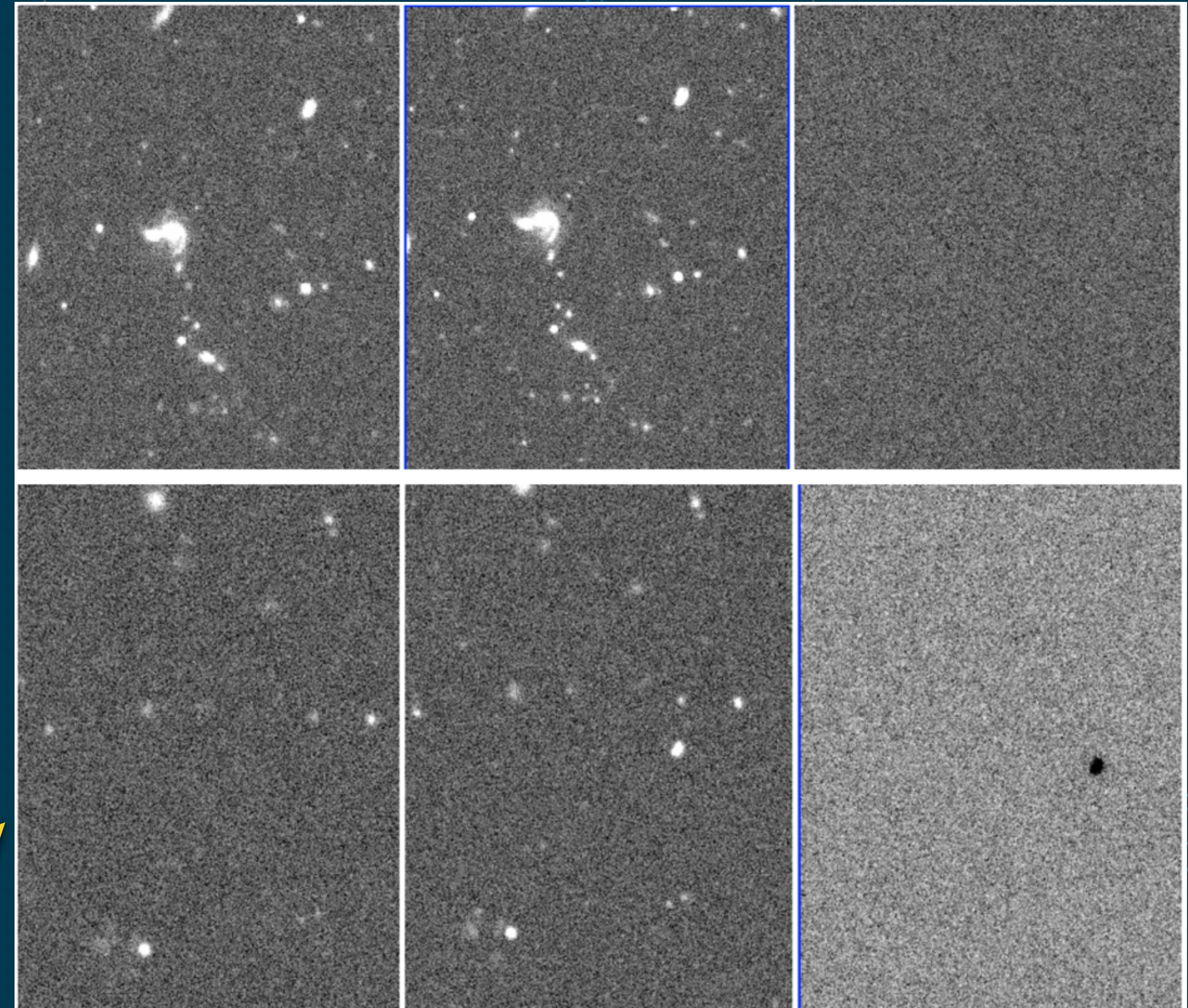


State of ip_diffim as of summer, 2016

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

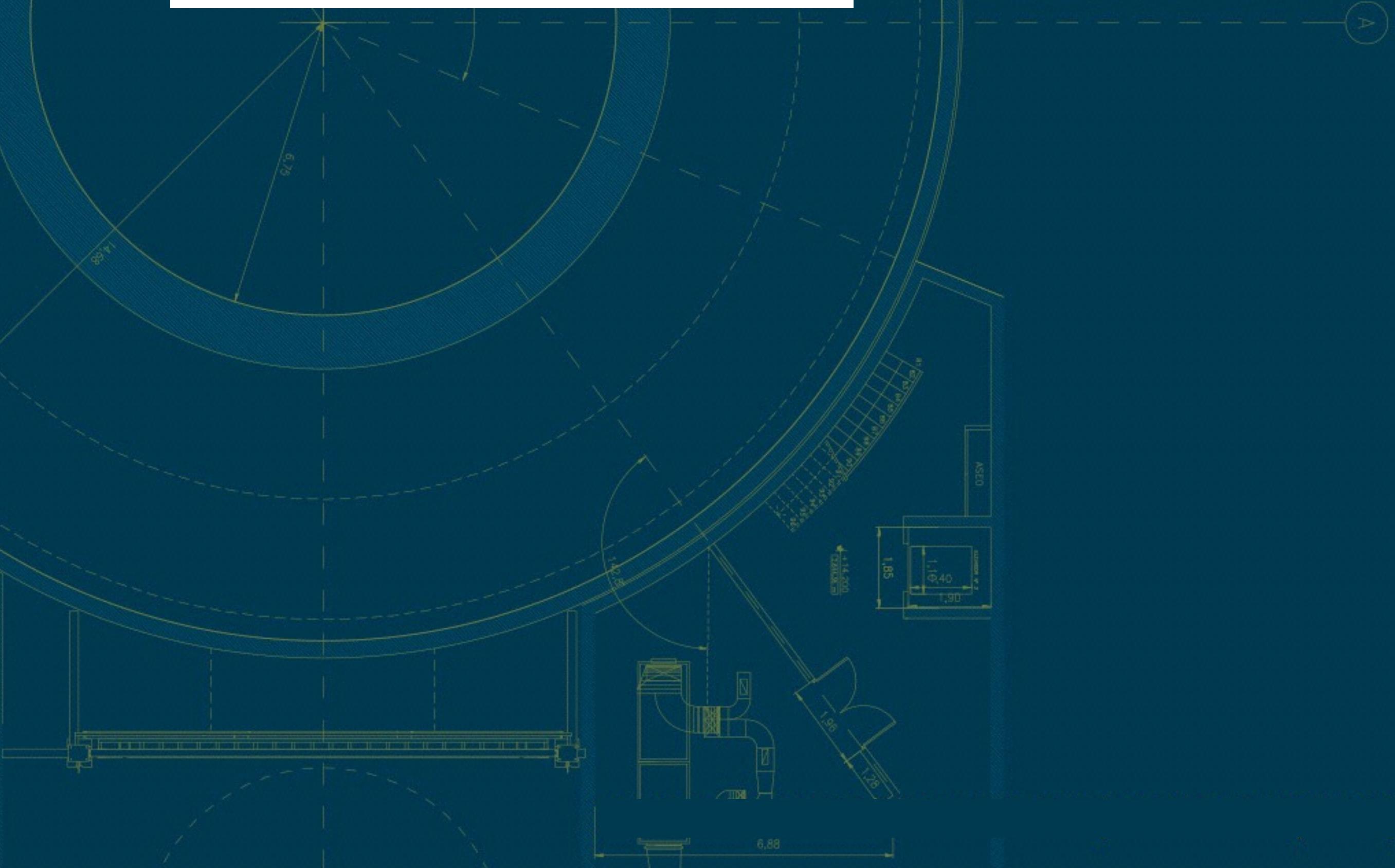
Francisco Forster (CMM) and Yusra
AlSayyad (UW)

High Cadence Transient Survey DECam
images subtracted with LSST Stack



Alard & Lupton image subtraction

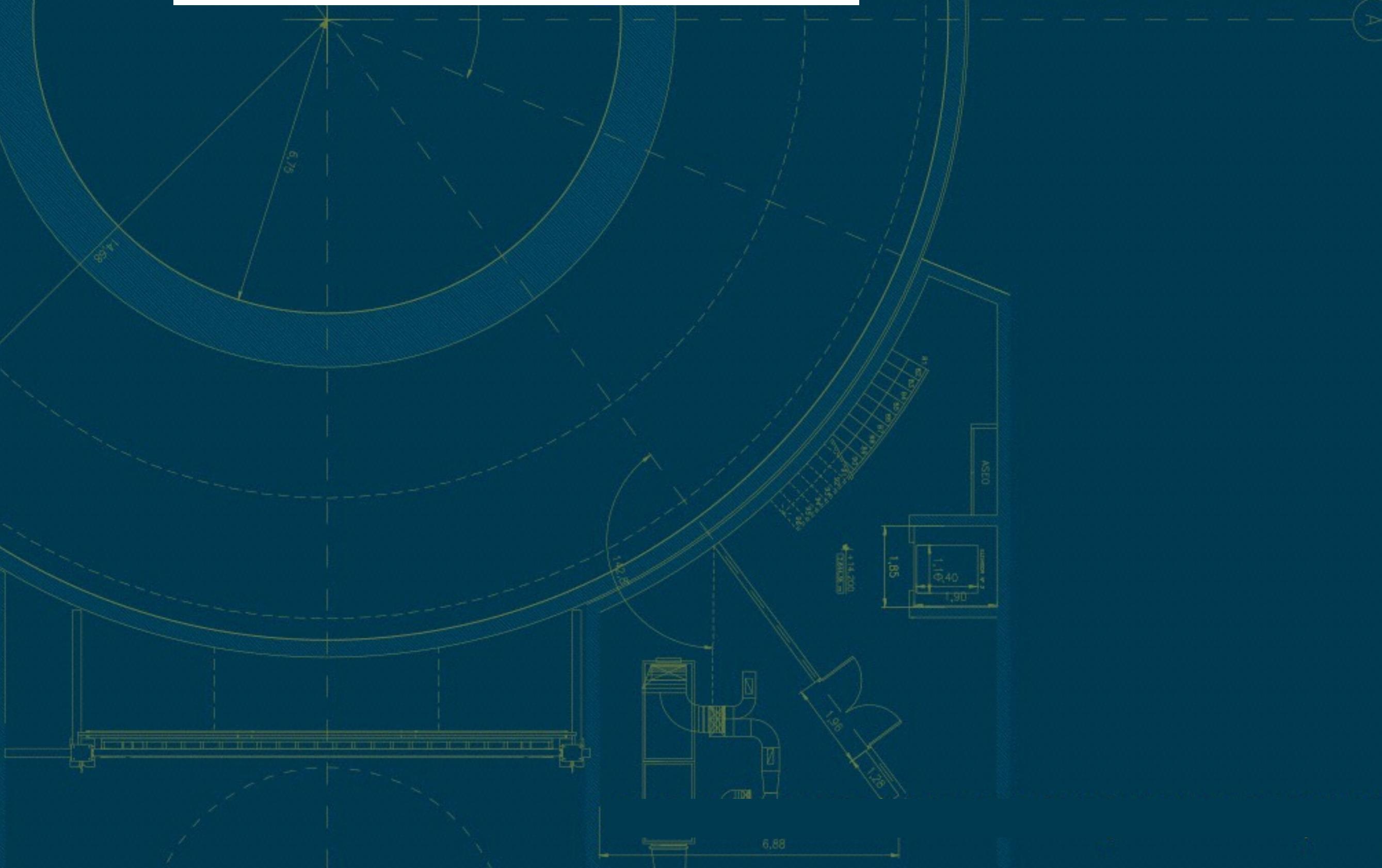
$$D = I_1 - \kappa \otimes I_2$$



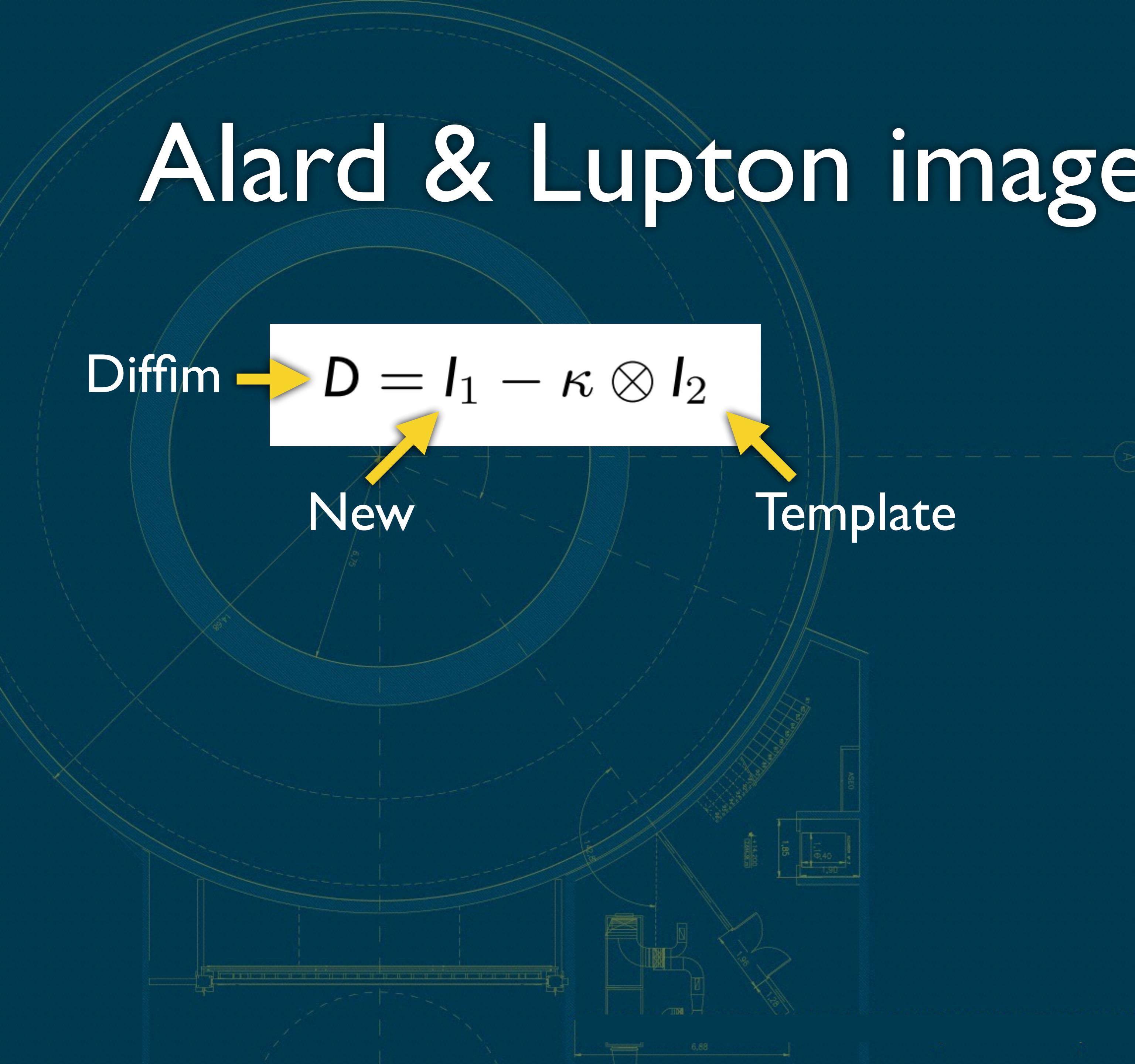
Alard & Lupton image subtraction

Diffim

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



Alard & Lupton image subtraction



A schematic diagram of the LSST optical bench. It shows concentric rings representing the telescope's field of view. A central camera is positioned at the focal plane. A horizontal dashed line extends from the camera through the telescope's focal length. On the left, a white rectangular box contains the equation $D = I_1 - \kappa \otimes I_2$. Three yellow arrows point from the words "Diffim", "New", and "Template" to the respective terms in the equation.

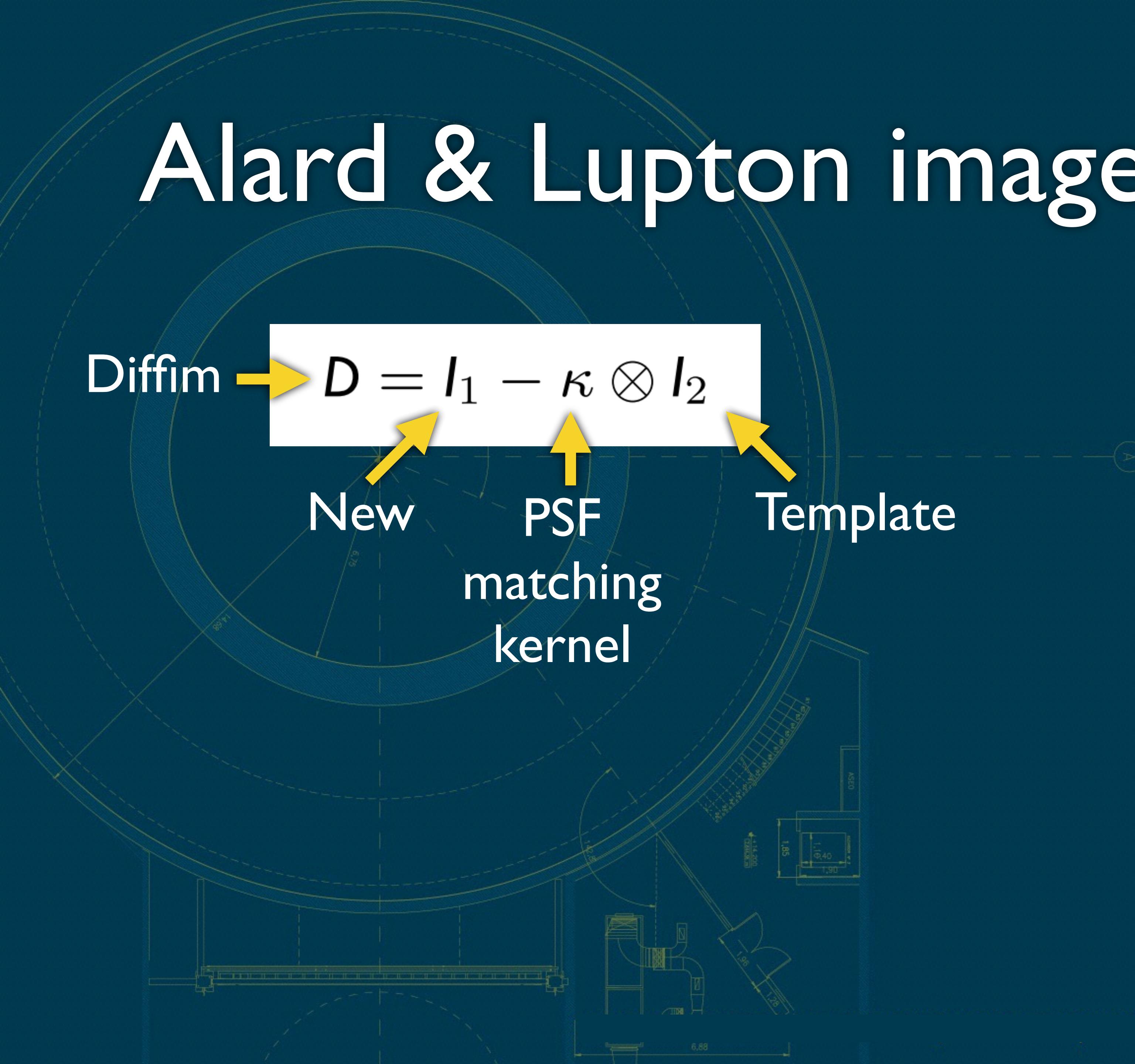
$$D = I_1 - \kappa \otimes I_2$$

Diffim →

New

Template

Alard & Lupton image subtraction



A diagram of the LSST camera optical bench is shown in the background, featuring concentric circles and various mechanical components. A white rectangular box is overlaid on the center of the diagram, containing the mathematical equation for image subtraction.

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

Diffim →

New PSF matching kernel

Template

Alard & Lupton image subtraction

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

New PSF matching kernel

Template

Expand κ 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

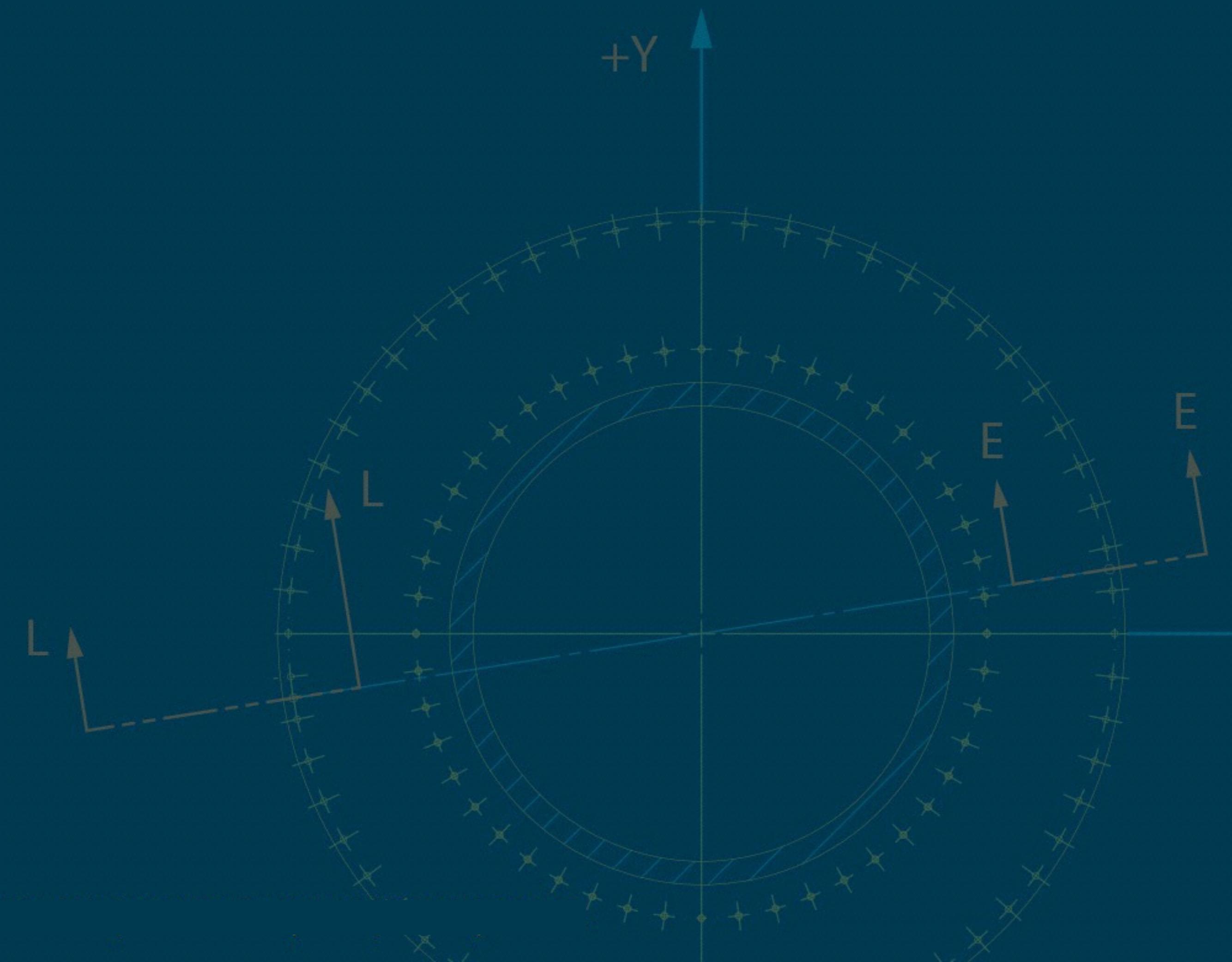
Minimize:

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

Expand κ as:

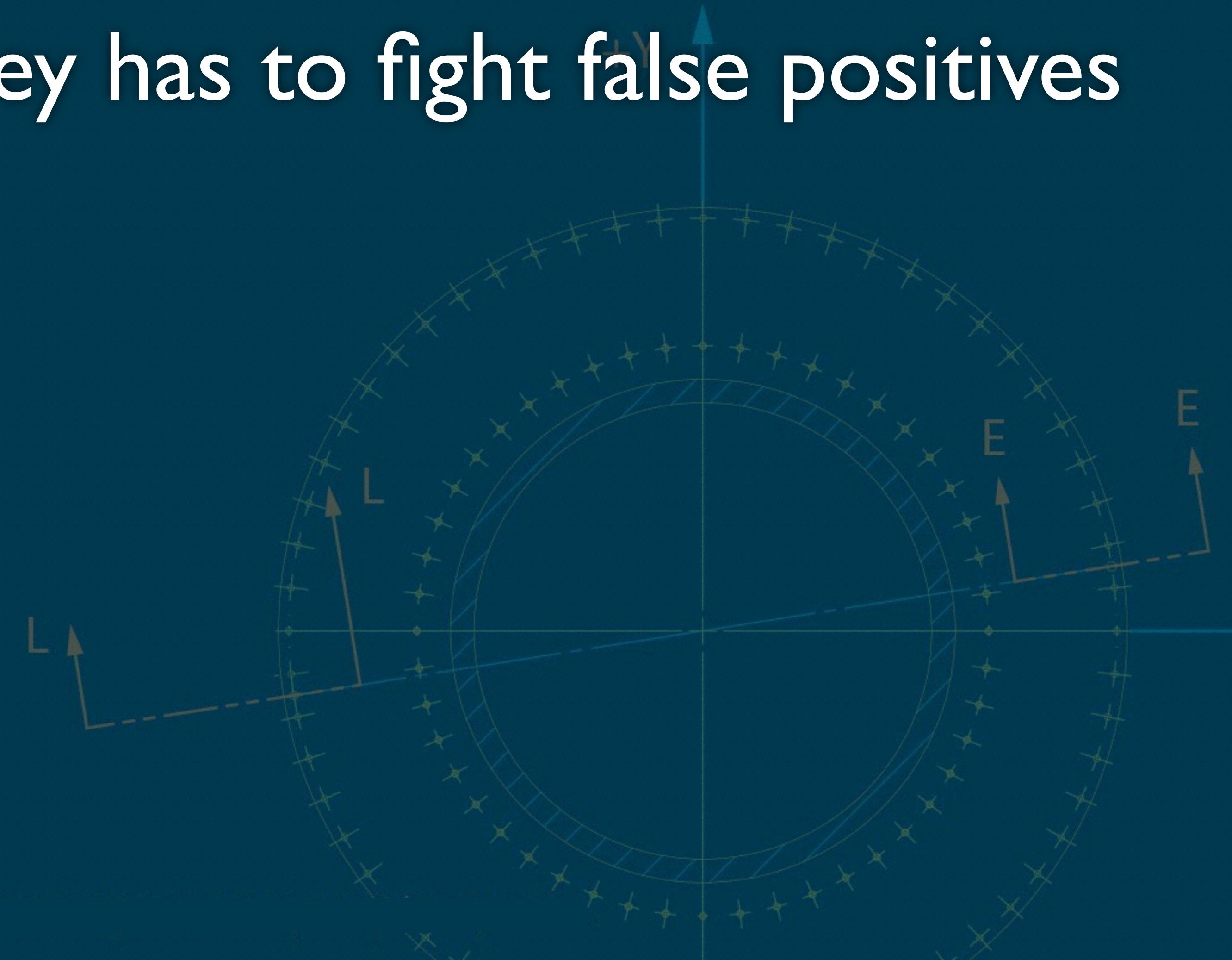
$$\kappa = \sum_r a_r B^r$$

Understood issues with A&L



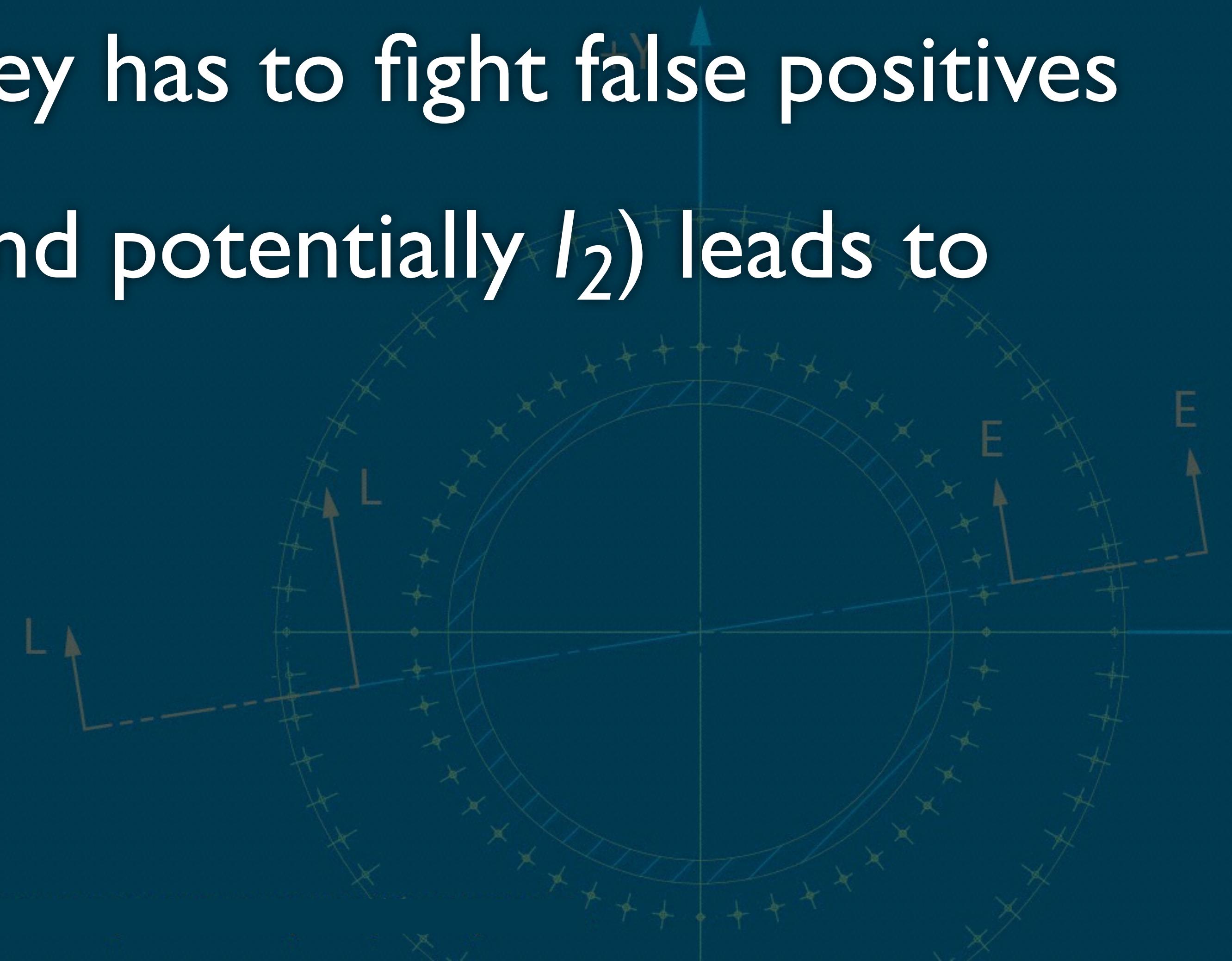
Understood issues with A&L

- Every transient survey has to fight false positives



Understood issues with A&L

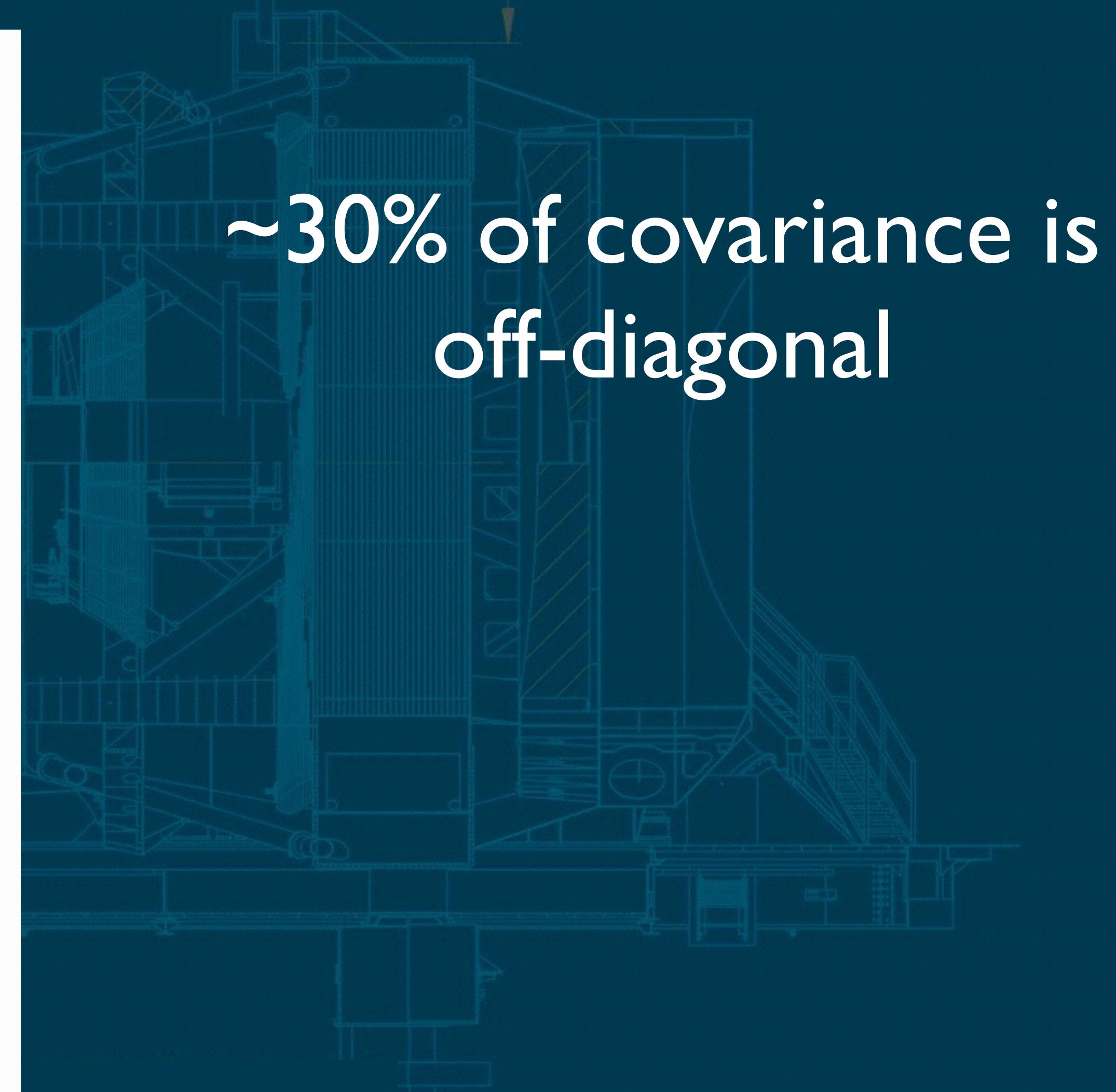
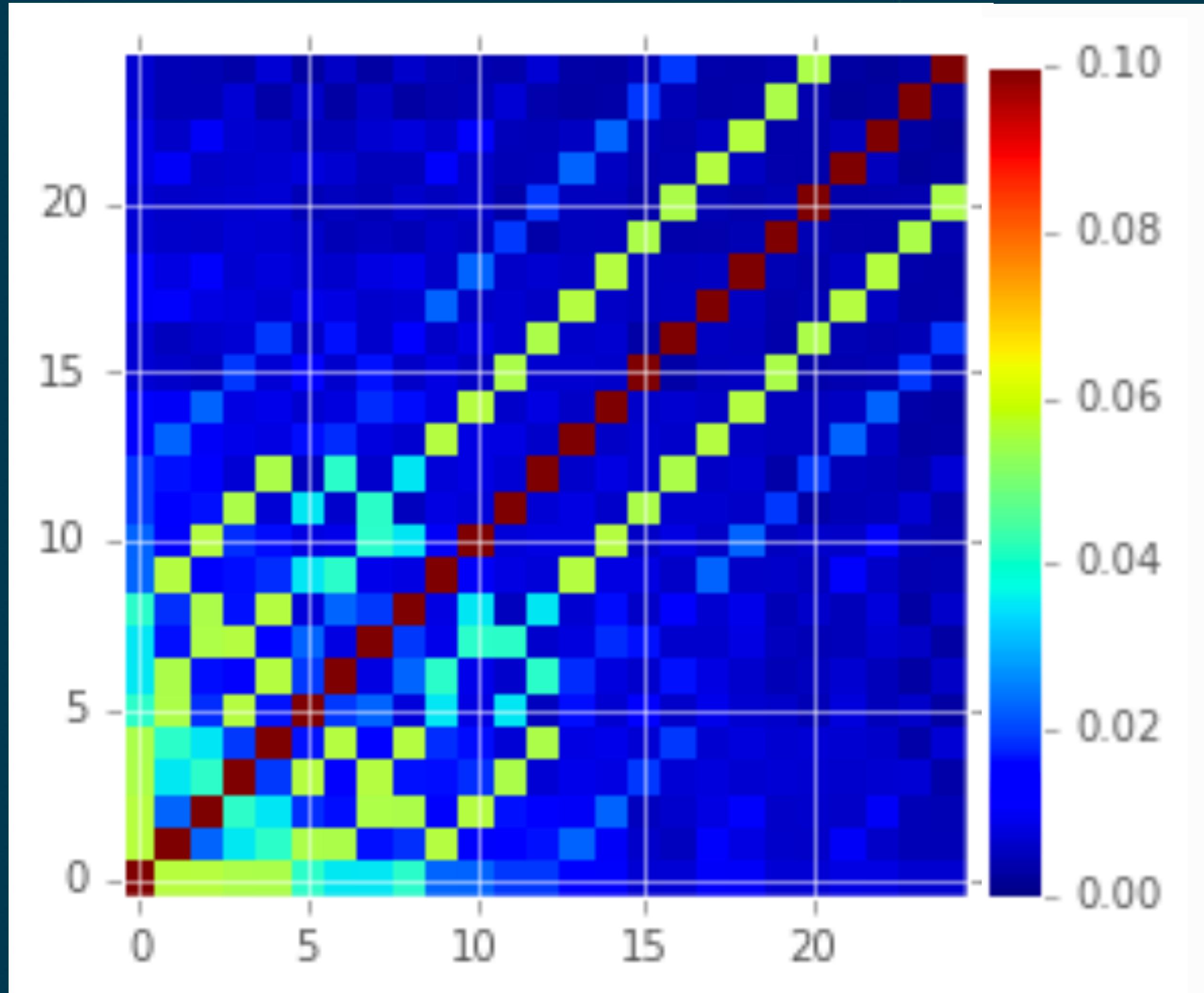
- Every transient survey has to fight false positives
- Convolution of I_1 (and potentially I_2) leads to correlated noise



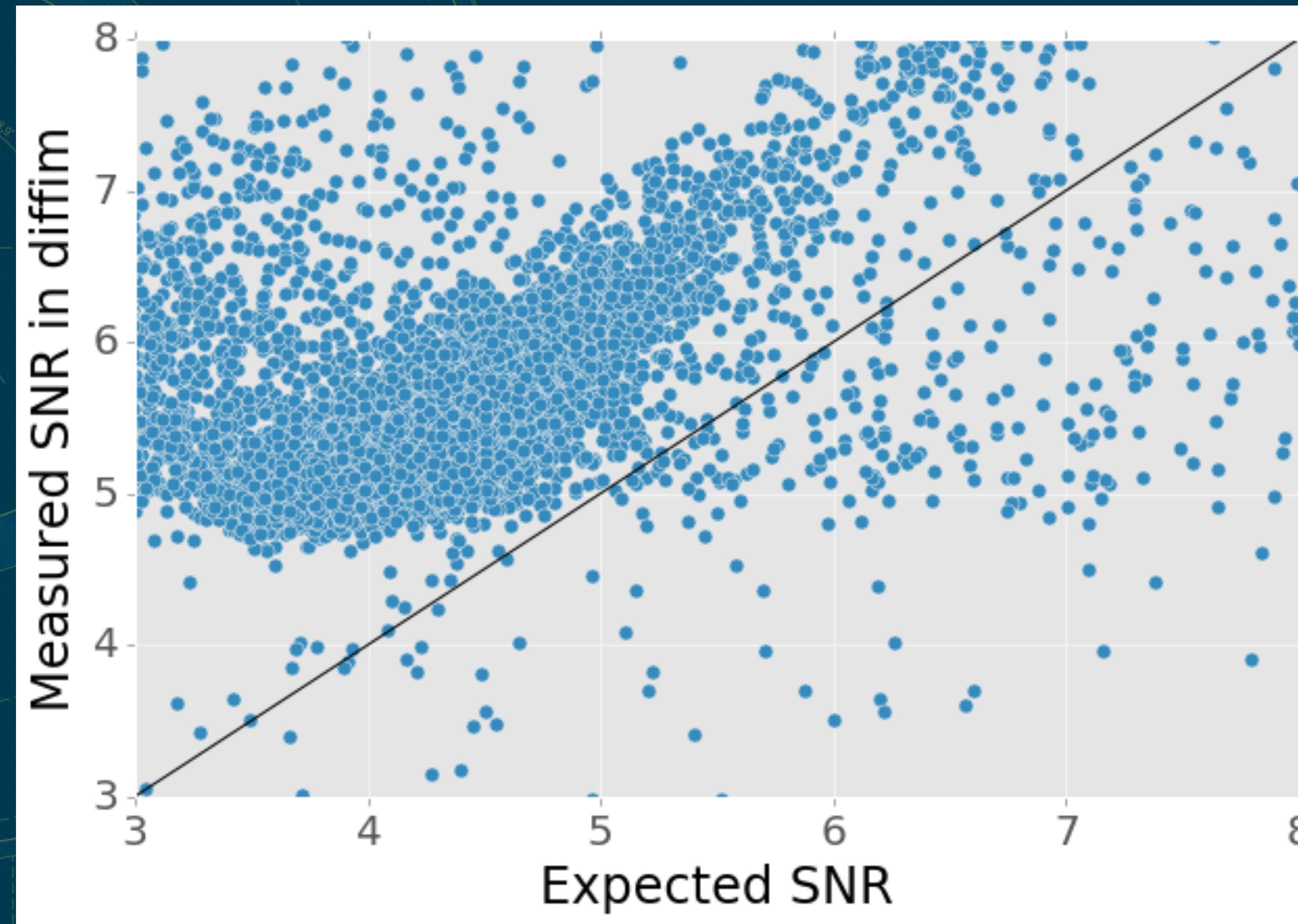
Understood issues with A&L

- 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



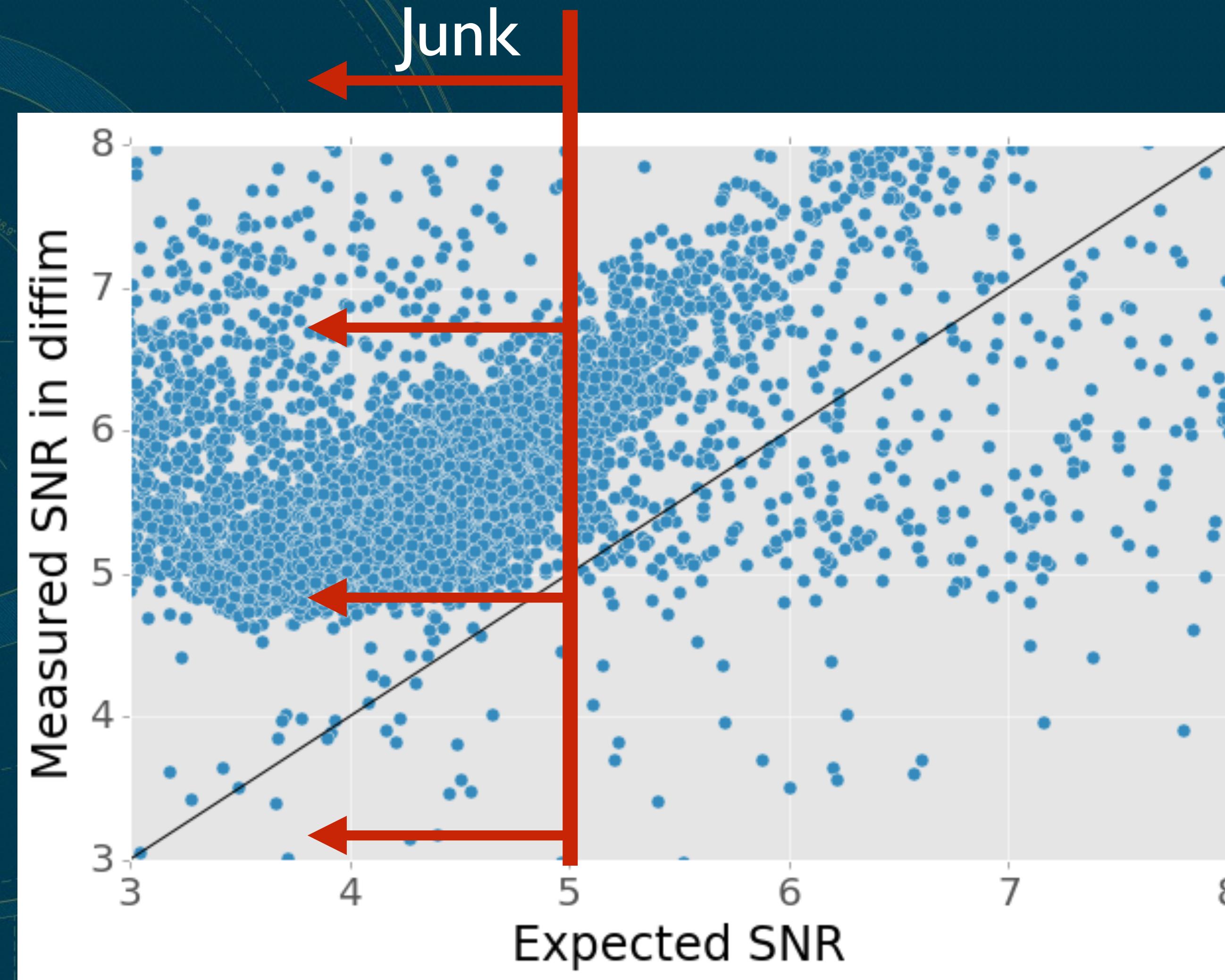
Effect of correlated noise



<http://dmtn-006.lsst.io>

<http://dmtn-021.lsst.io>

Effect of correlated noise



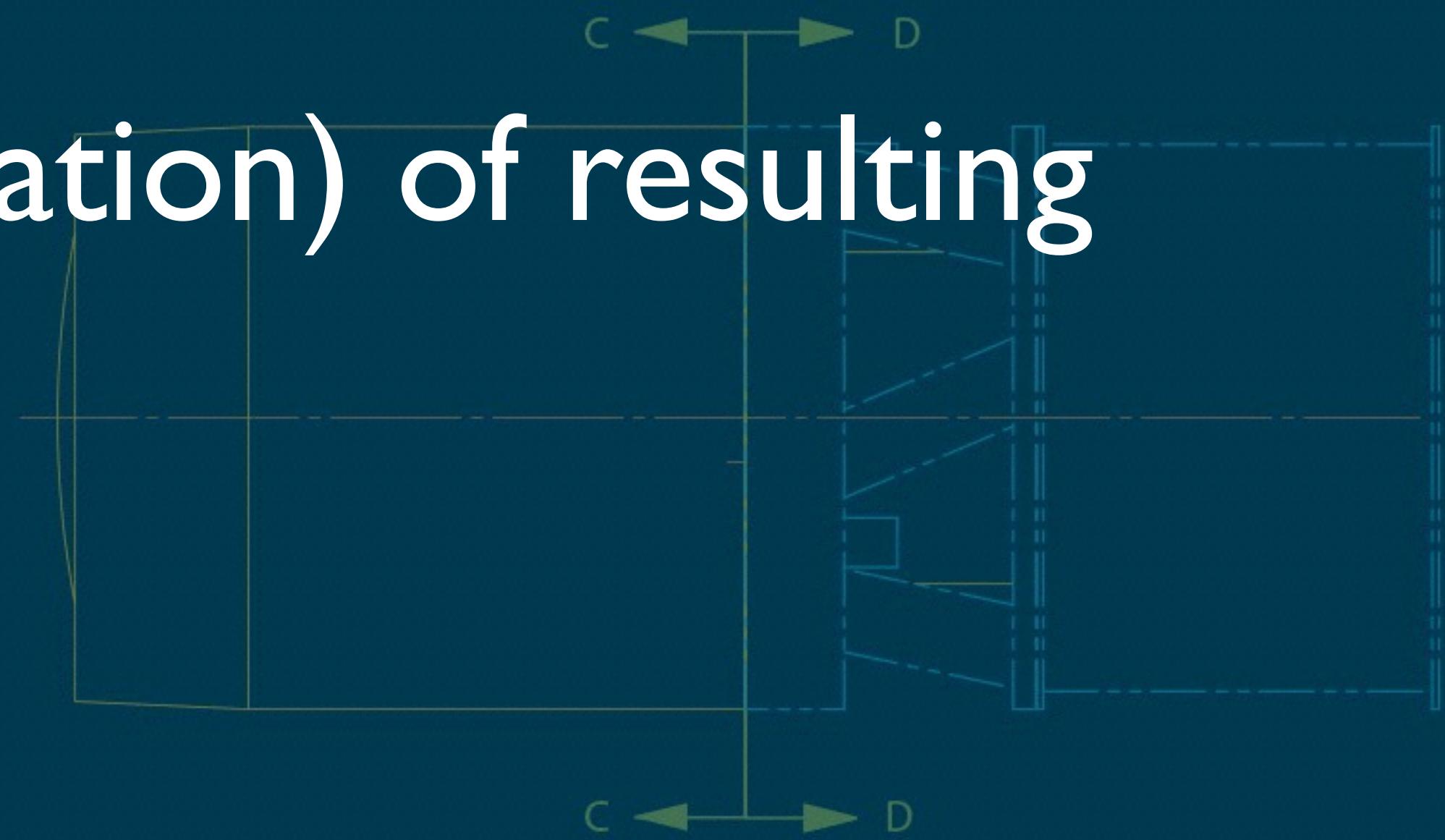
<http://dmtn-006.lsst.io>

<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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$$\hat{D} = \frac{F_r \hat{P}_r \hat{N} - F_n \hat{P}_n \hat{R}}{\sqrt{\sigma_n^2 F_r^2 |\hat{P}_r|^2 + \sigma_r^2 F_n^2 |\hat{P}_n|^2}}$$

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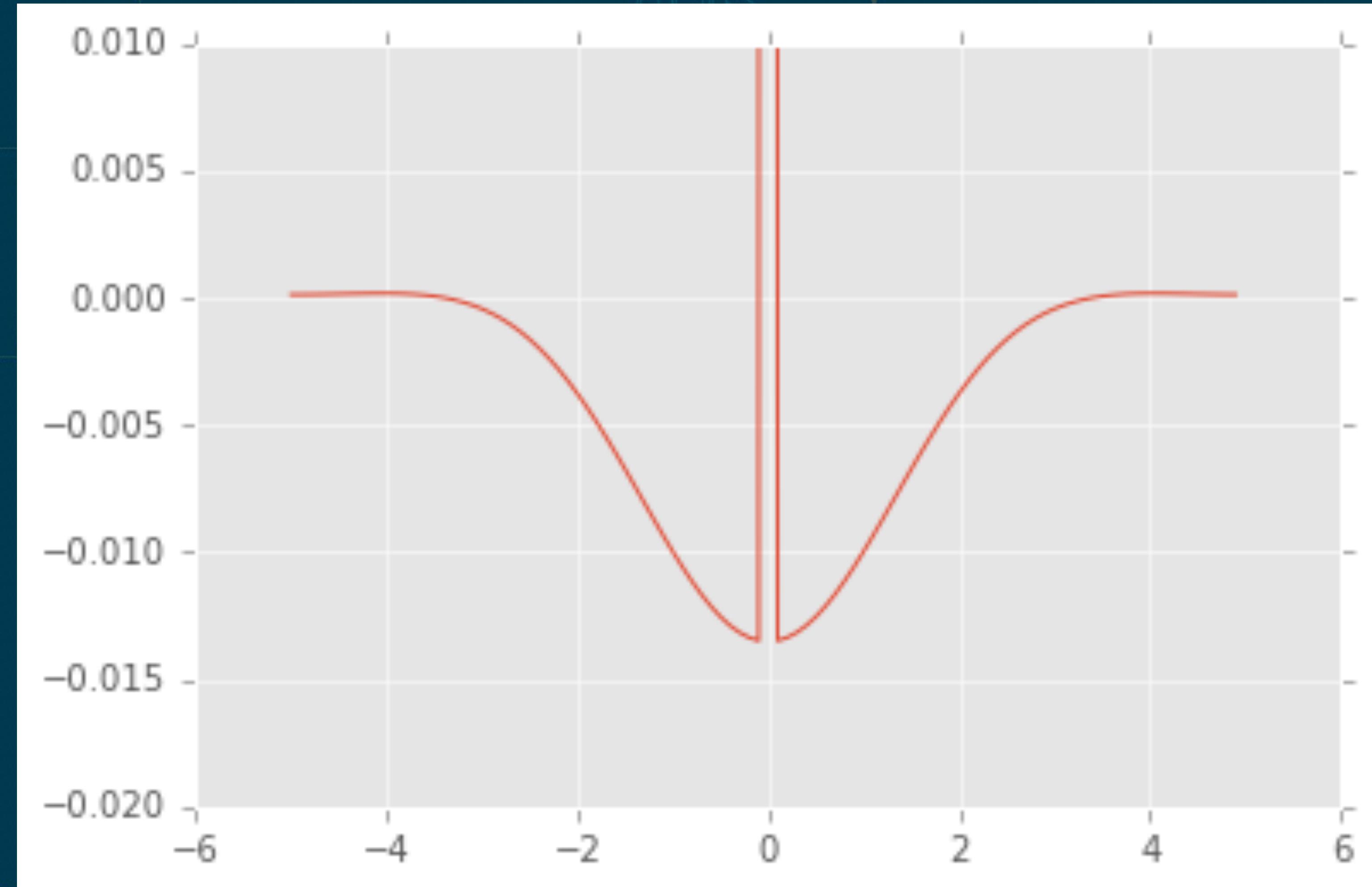
The A&L/ZOGY “Afterburner”

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

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

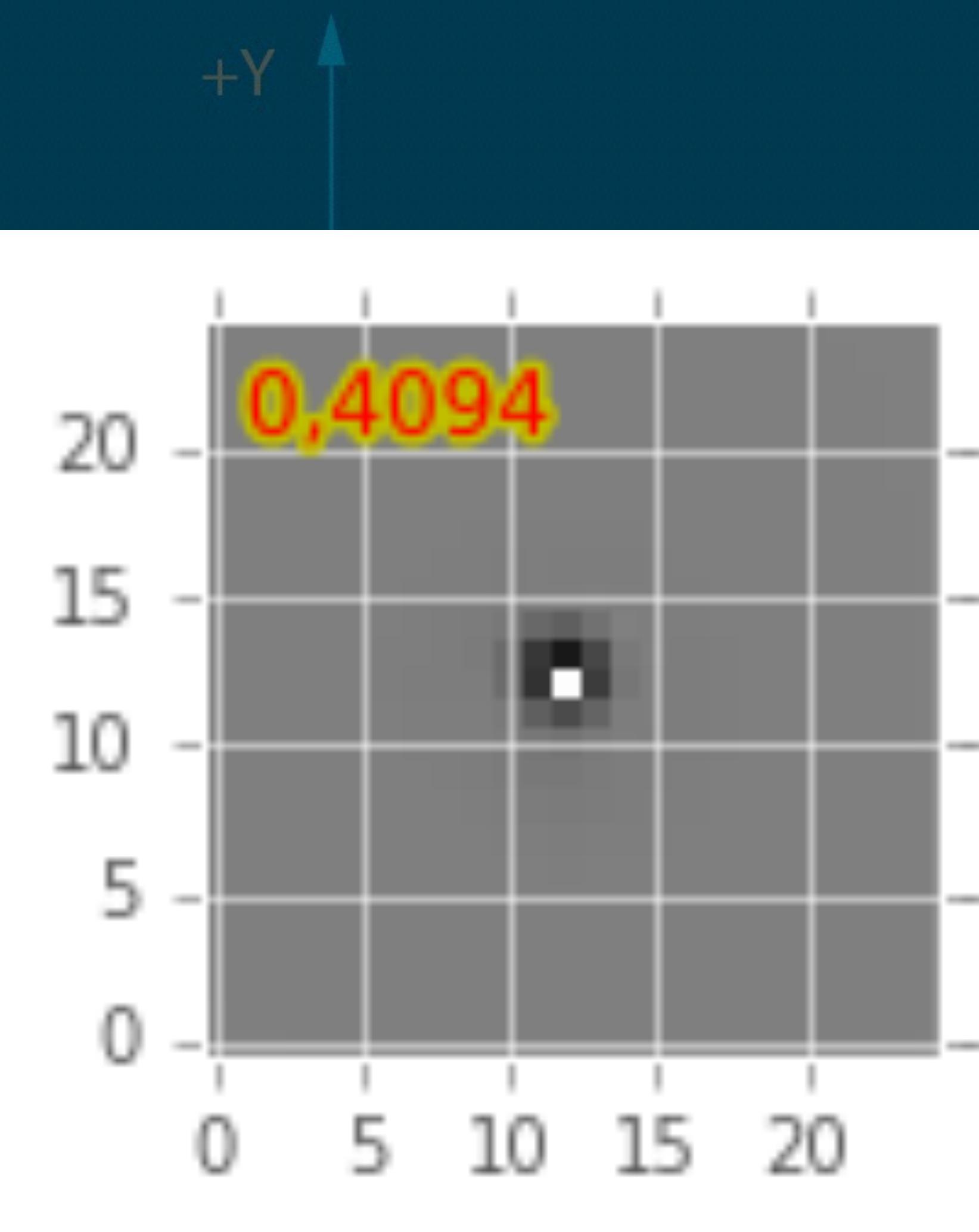
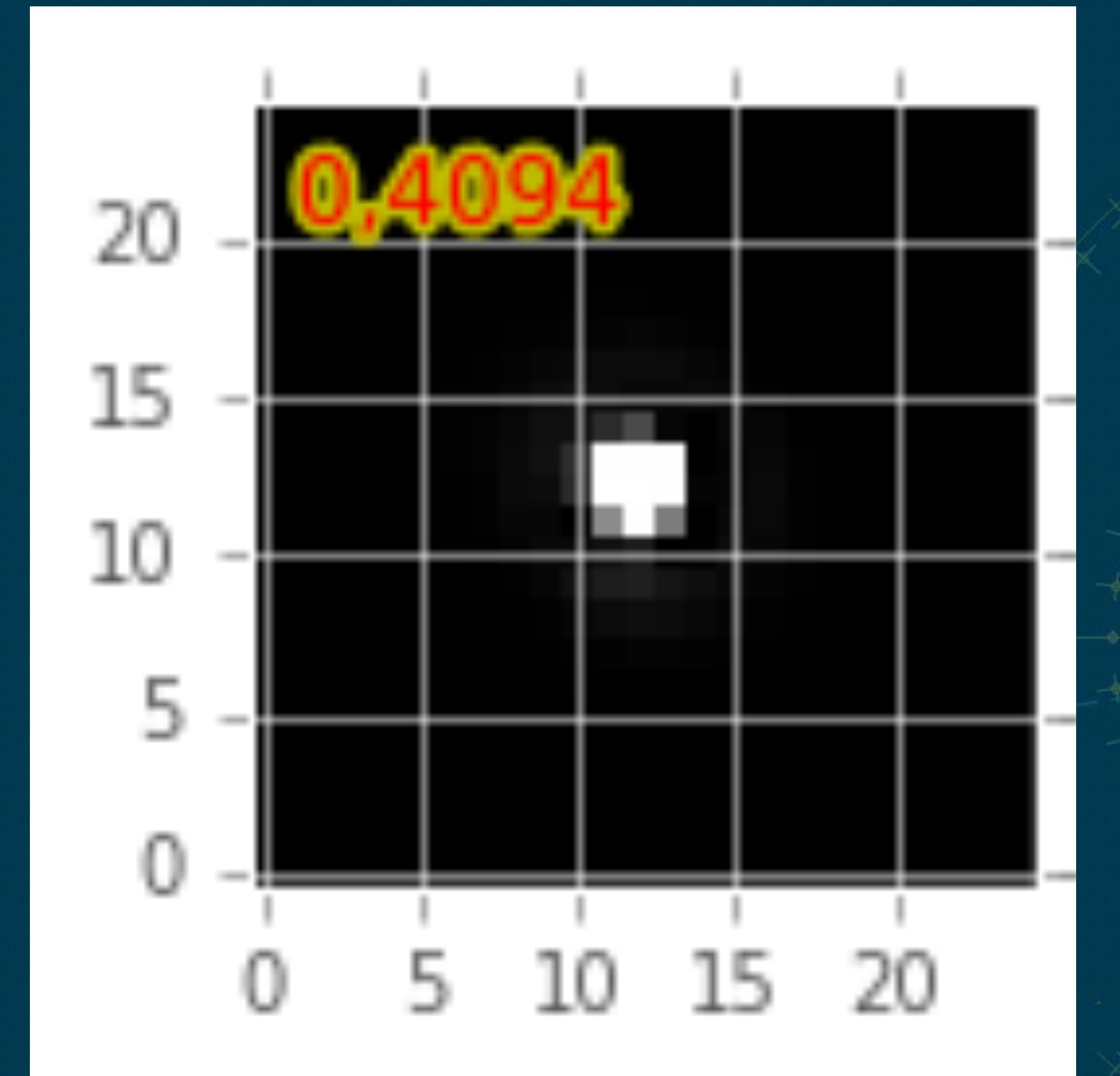
Decorrelating the A&L diffim

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

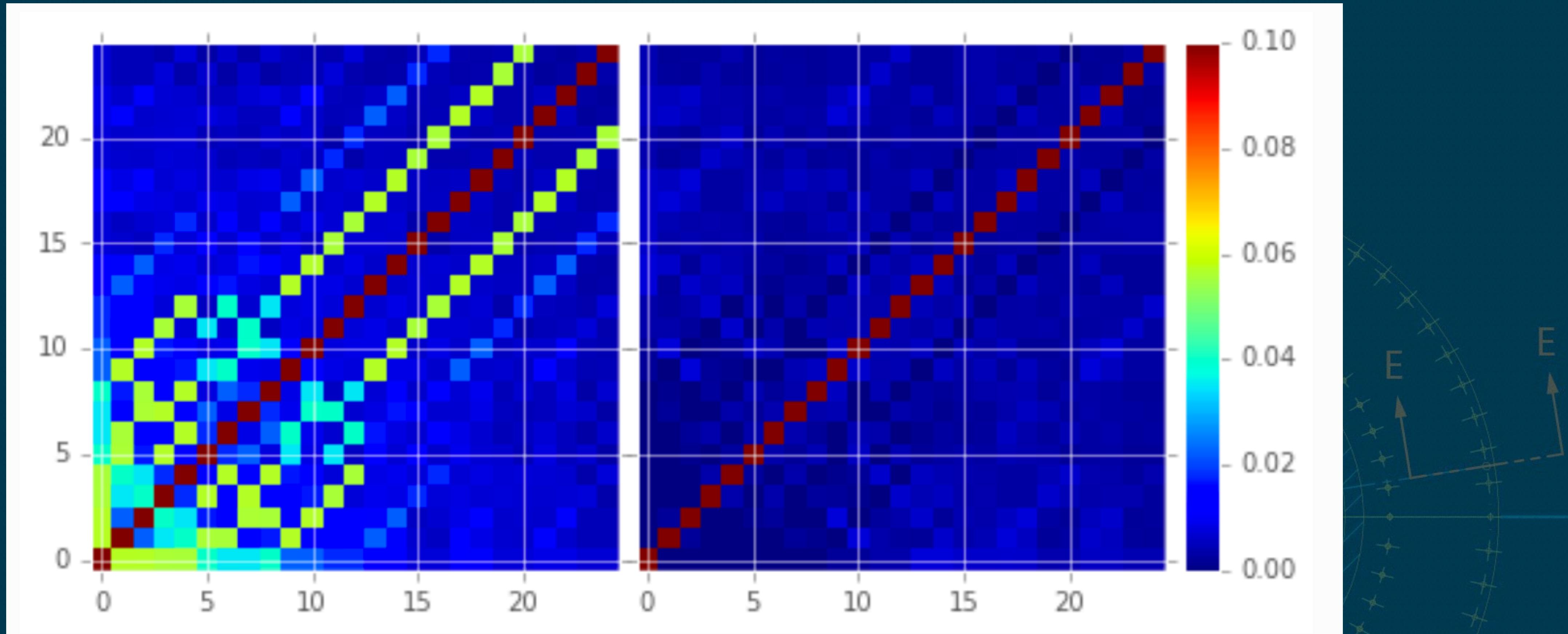


Decorrelating the A&L diffim

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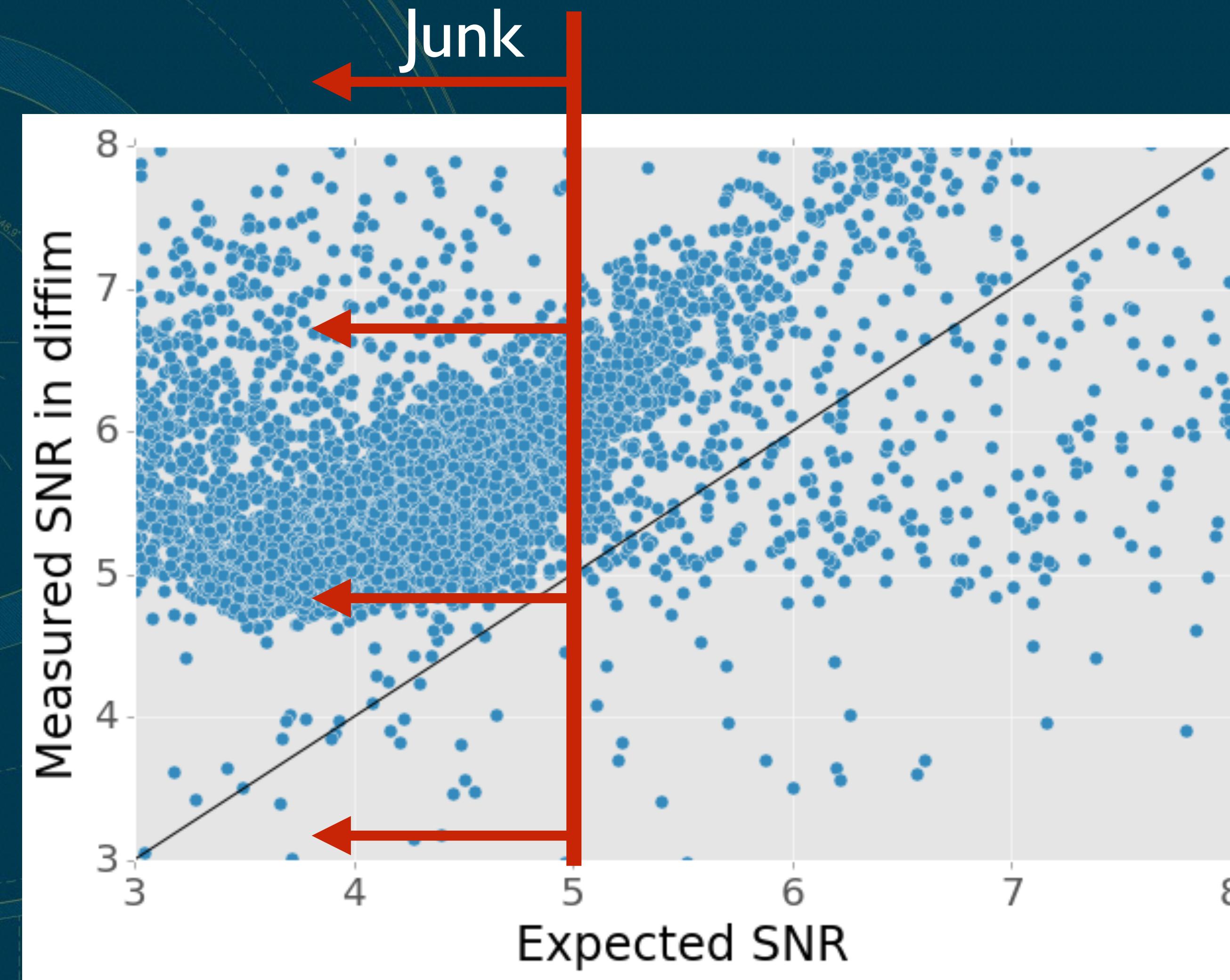


Decorrelating the A&L diffim



Neighboring pixel covariances

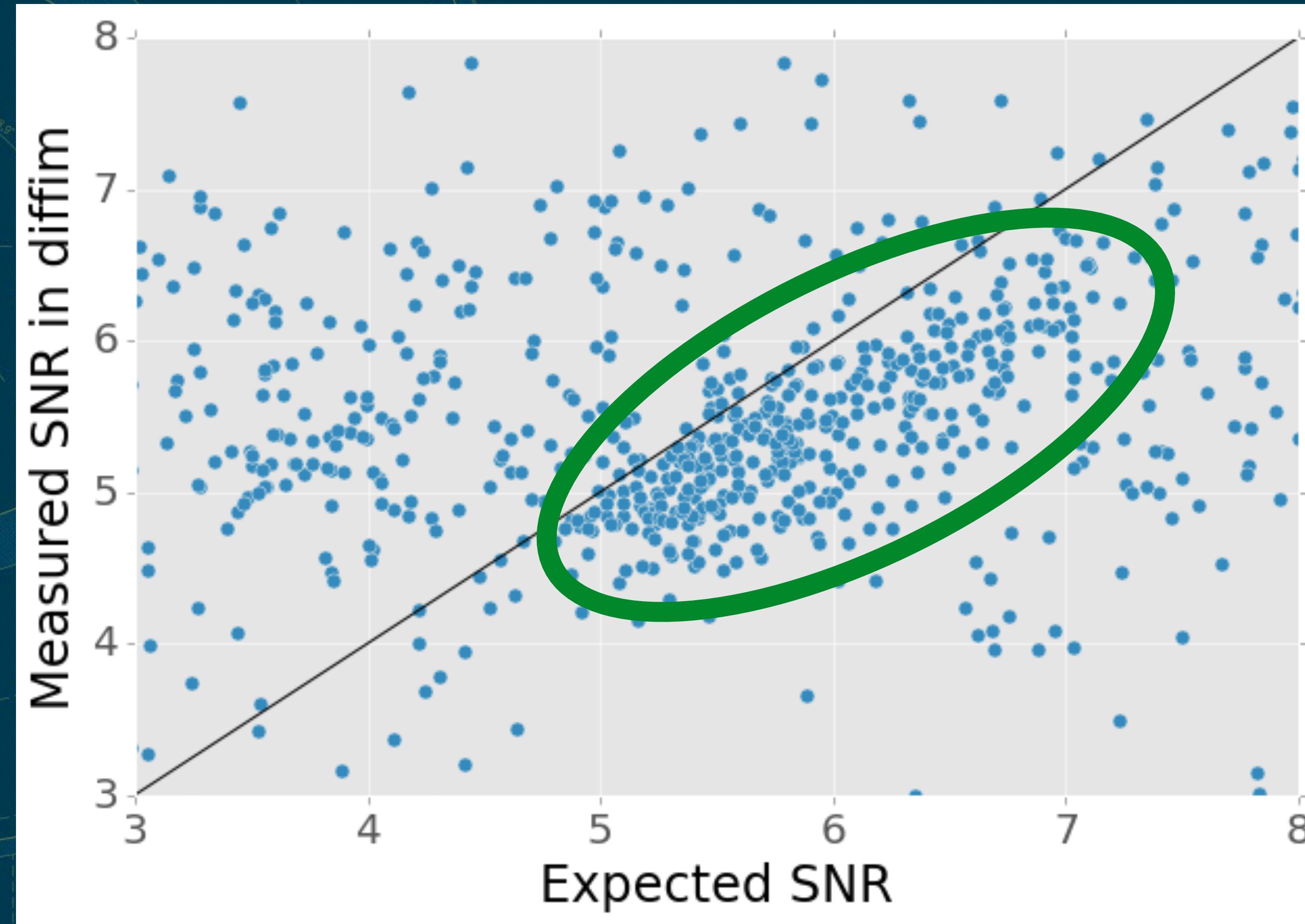
Without Decorrelation



<http://dmtn-006.lsst.io>

<http://dmtn-021.lsst.io>

With Decorrelation



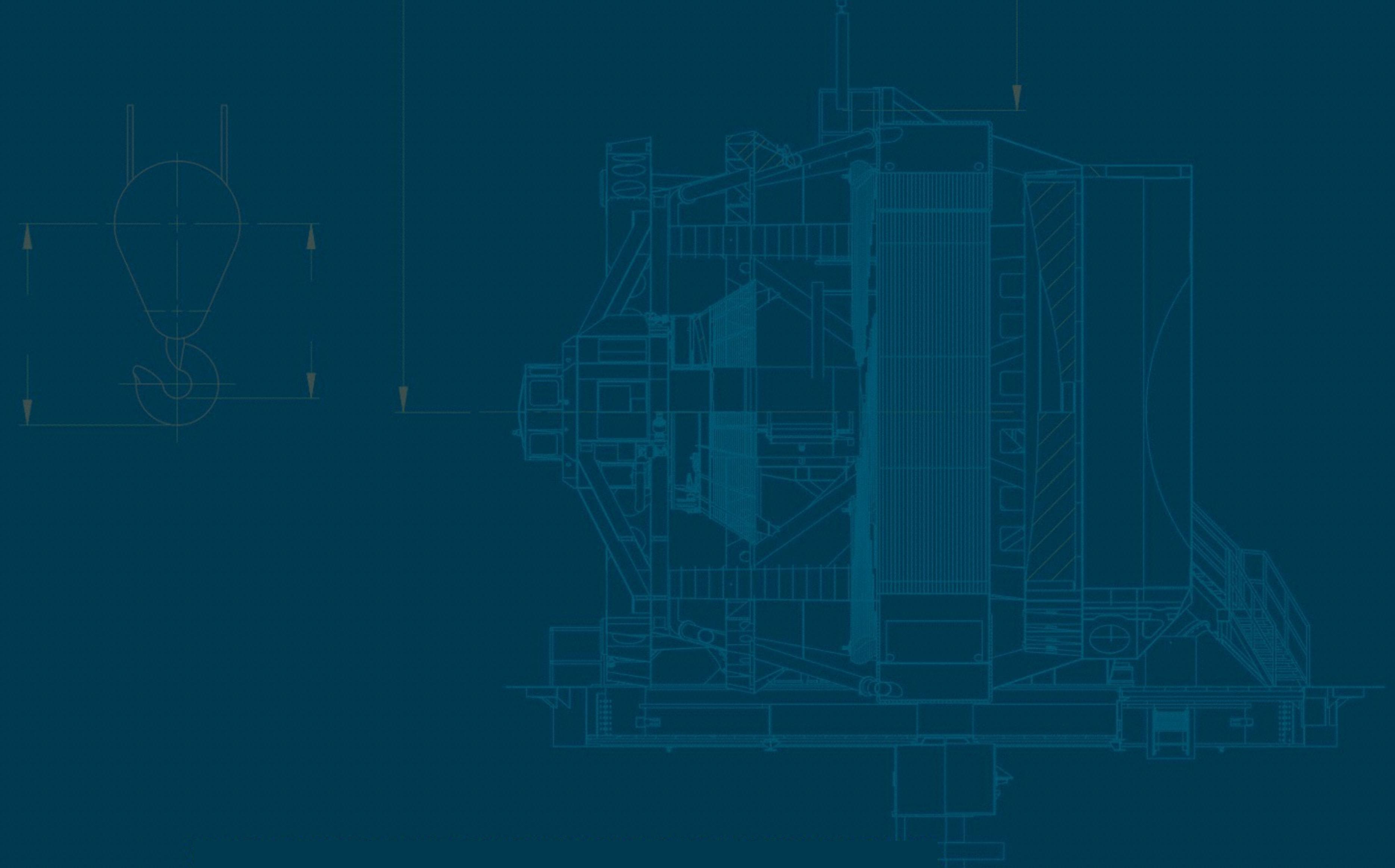
Real detections
at the right SNR

- Decorrelation reduces false detection rate from $\sim 20\text{k/sq deg}$ to $< 1000\text{/sq deg}$
- Much closer to the expected rate of astrophysical transients
- With cuts for finding Solar System objects, puts us in the $\sim \text{few hundred/sq deg}$ 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



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

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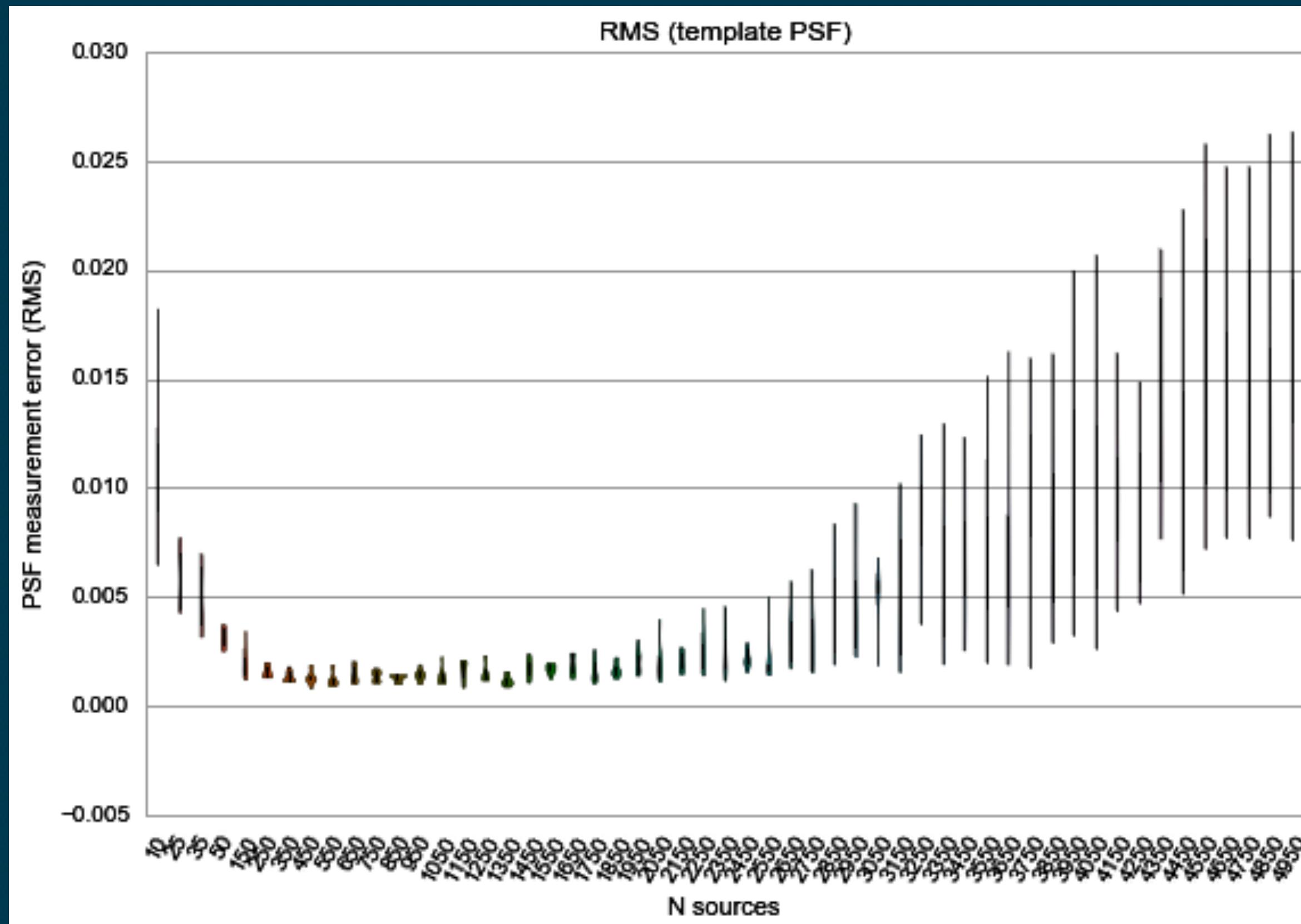
ZOGY vs. A&L shoot-out

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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”.

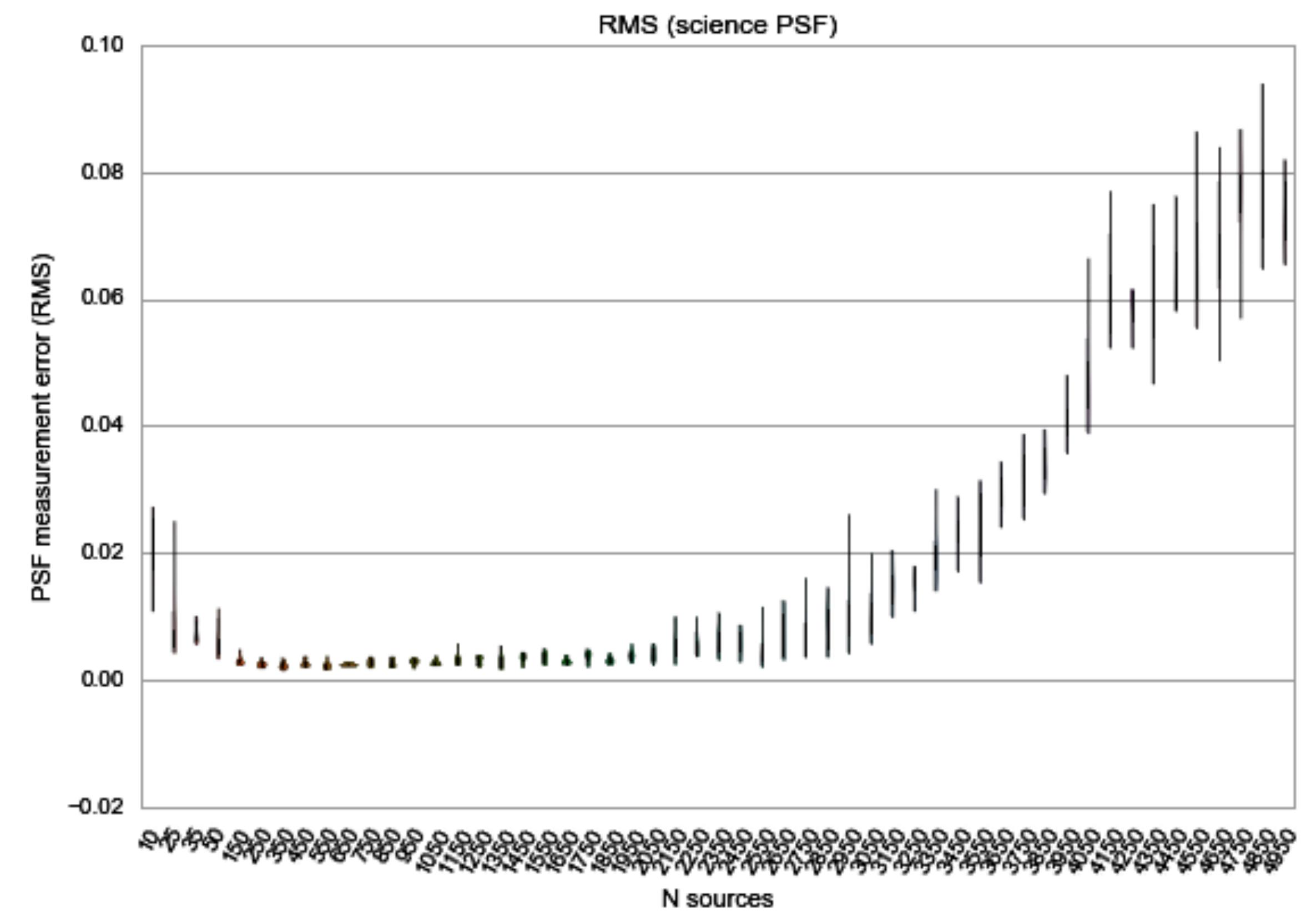
ZOGY vs. A&L shoot-out

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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

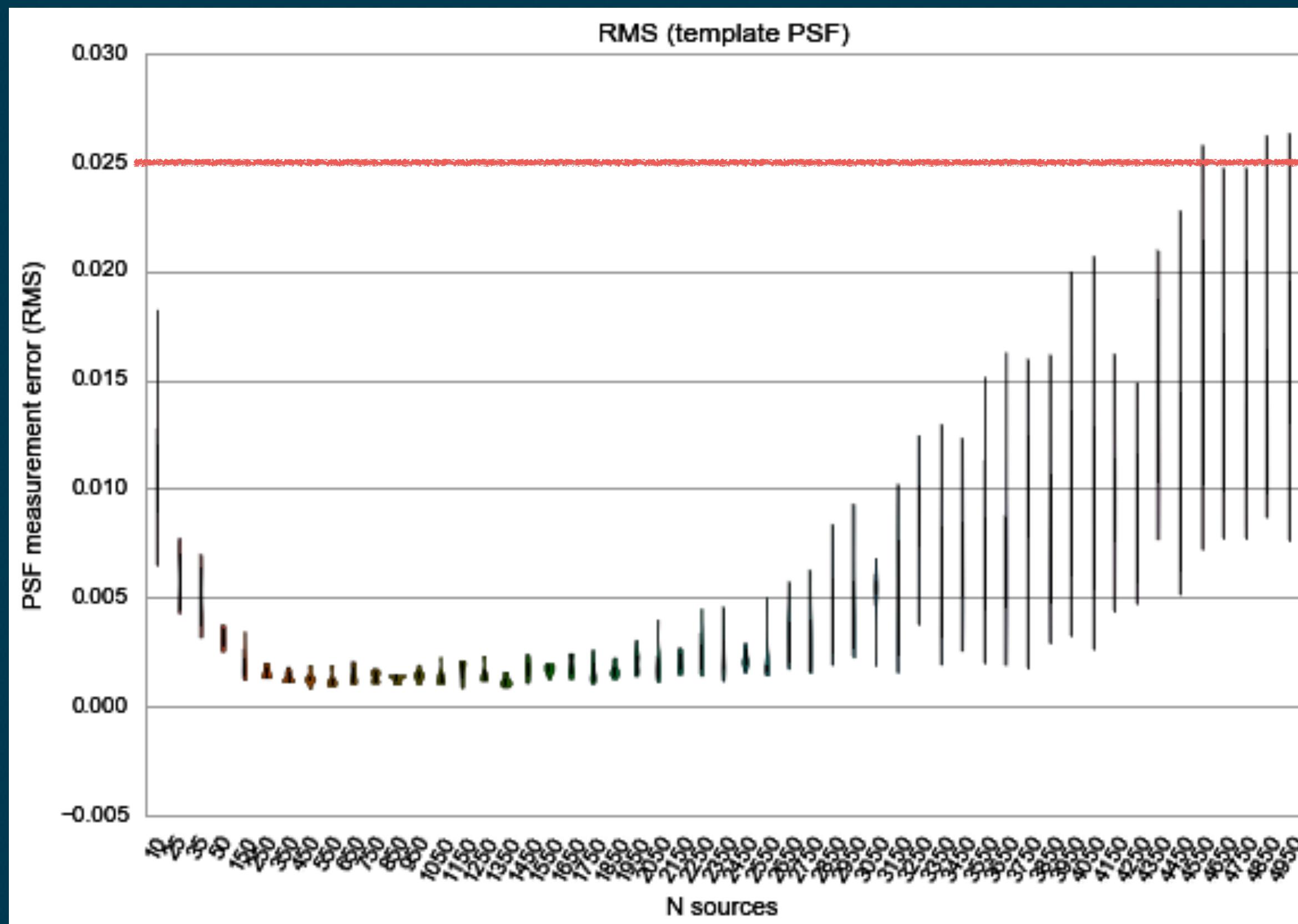


Template: 0.75" FWHM

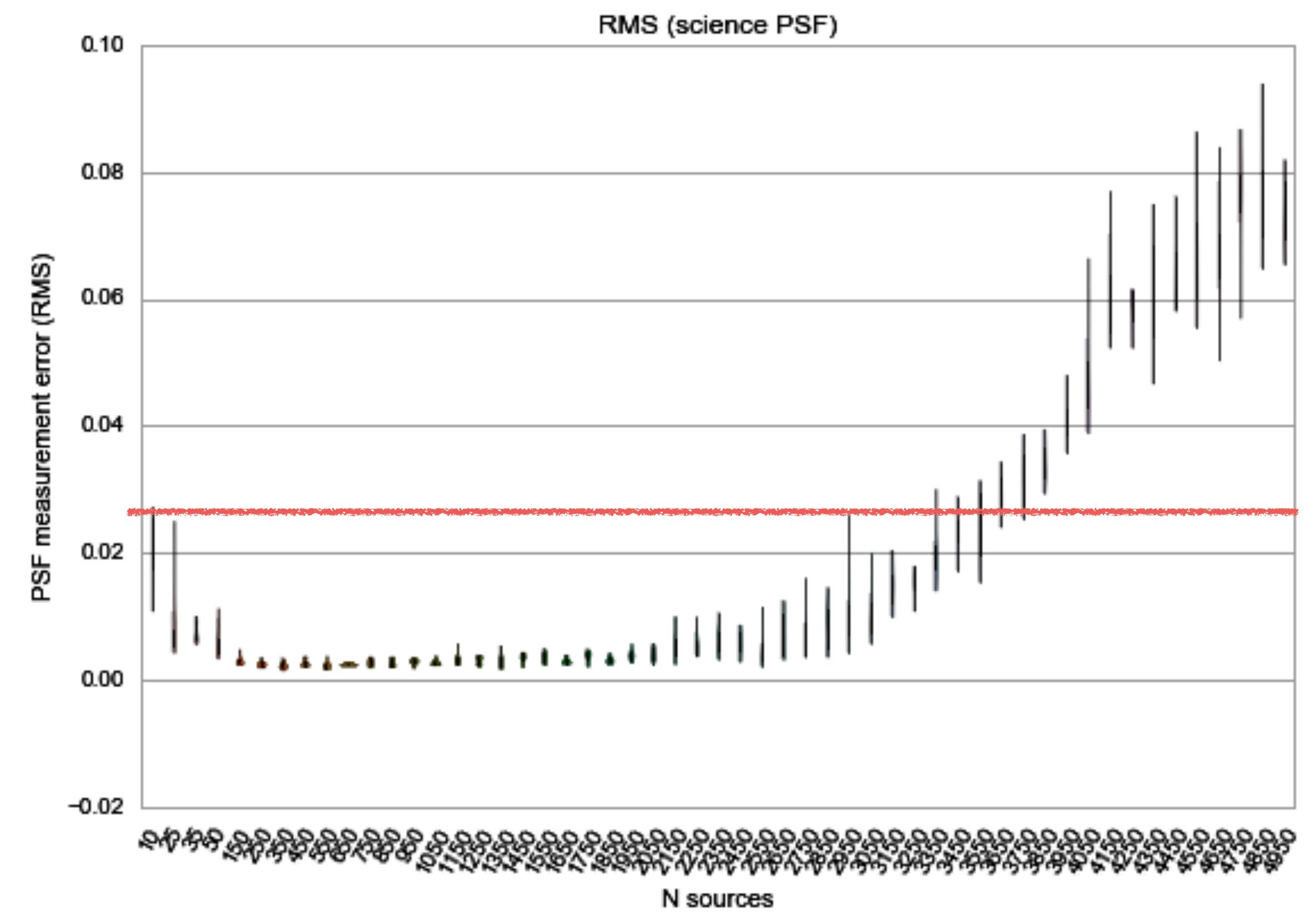


Science: 1.04" FWHM

PSF Measurement in LSST Stack

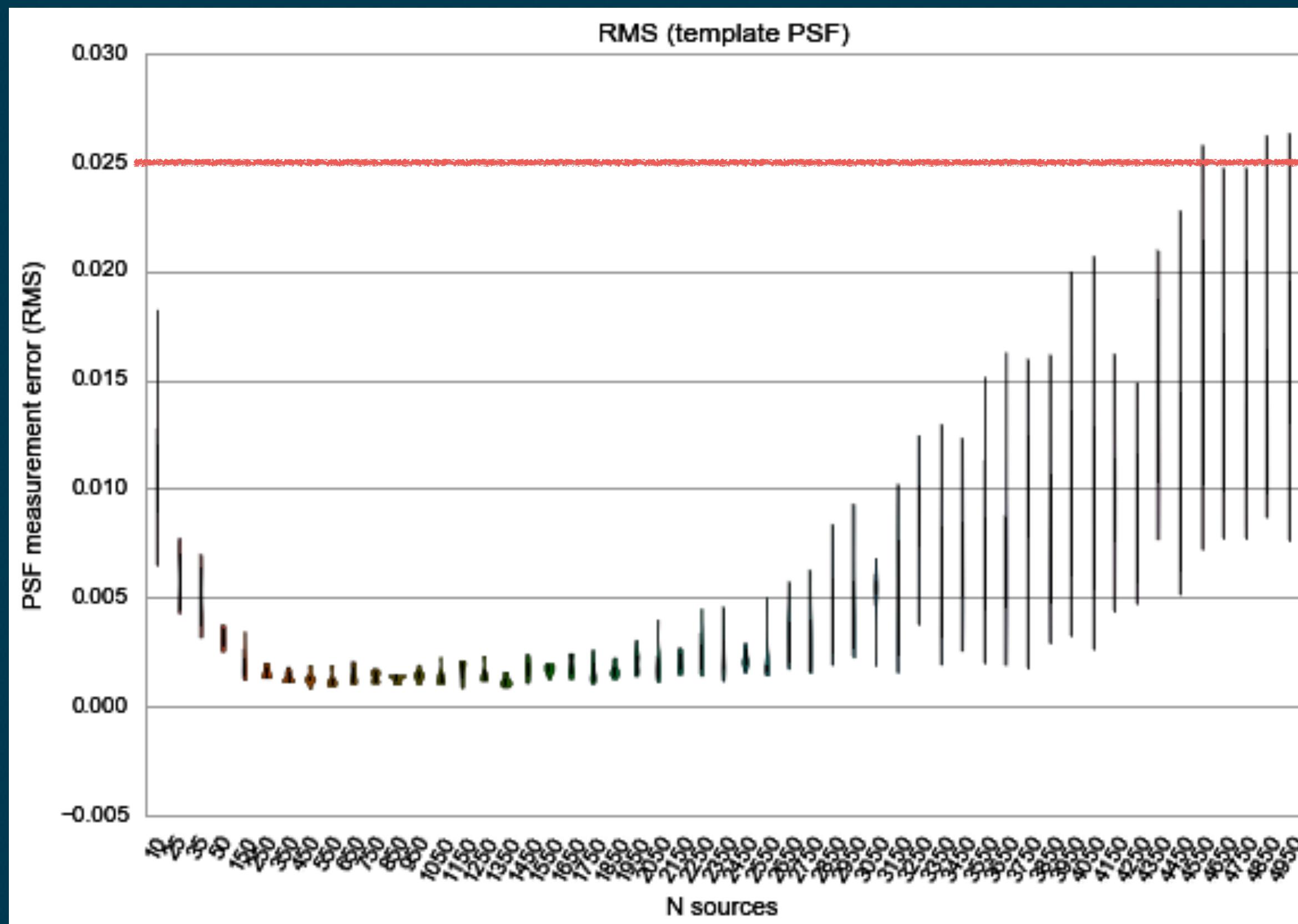


Template: 0.75" FWHM

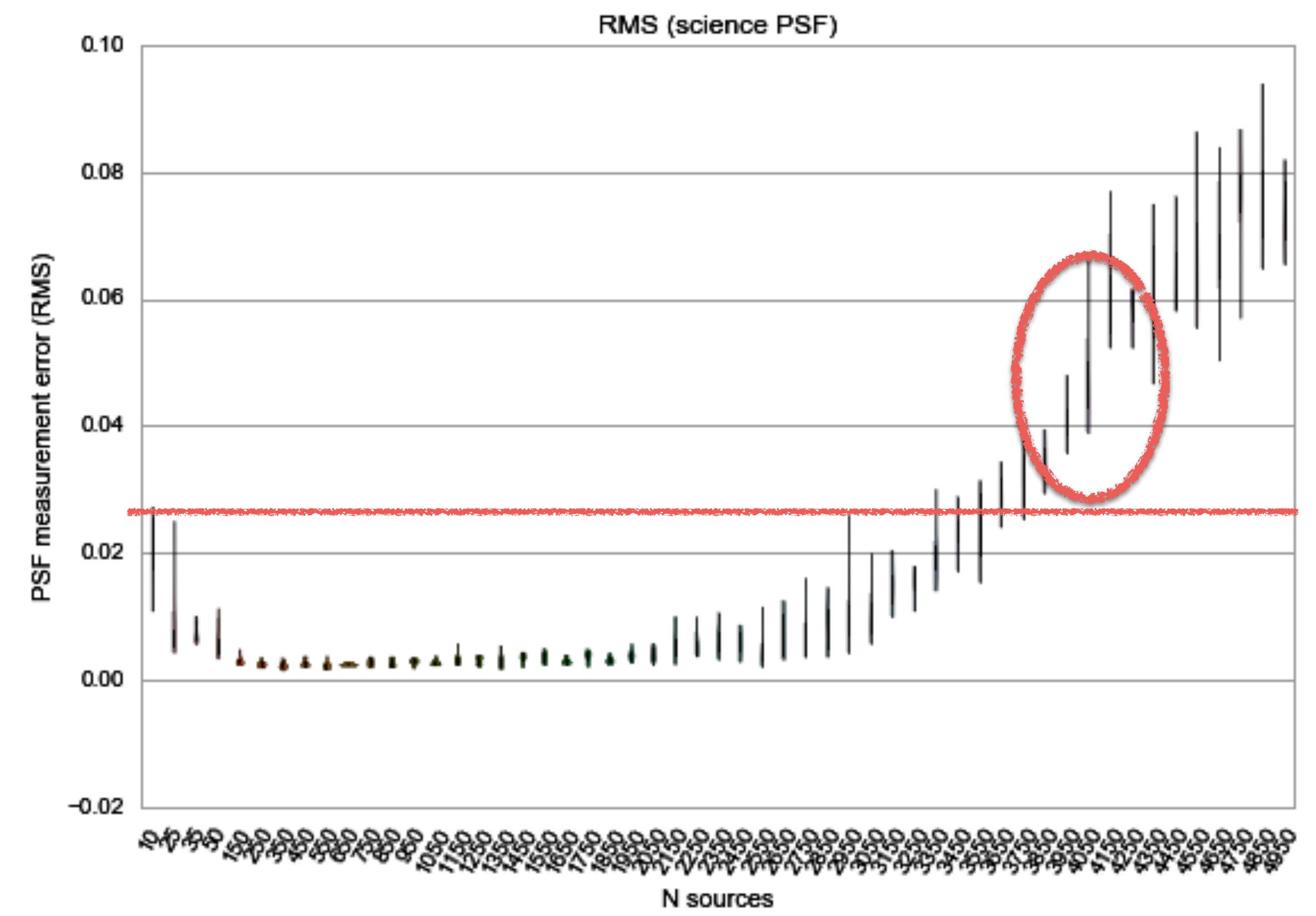


Science: 1.04" FWHM

PSF Measurement in LSST Stack

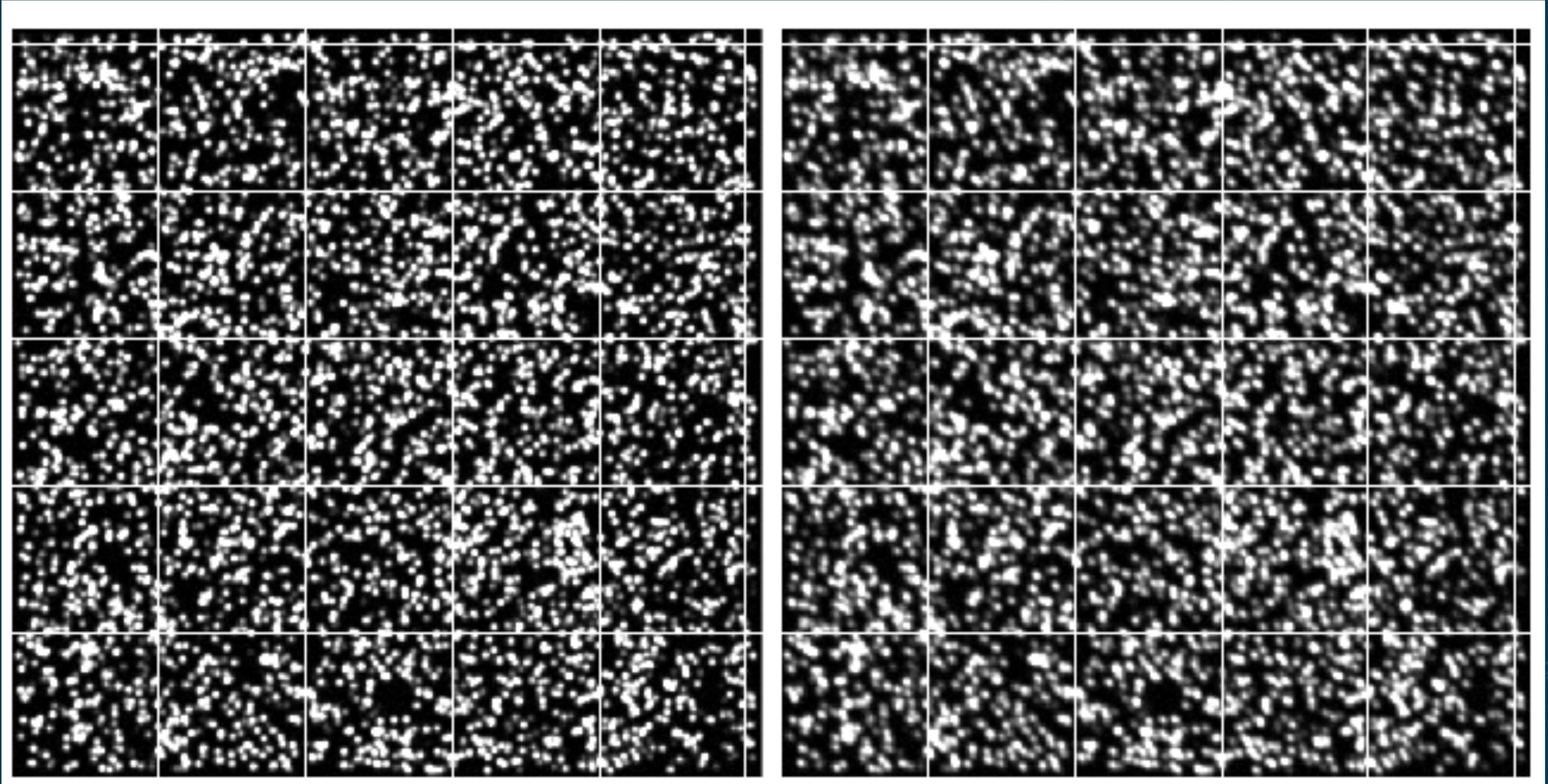


Template: 0.75" FWHM



Science: 1.04" FWHM

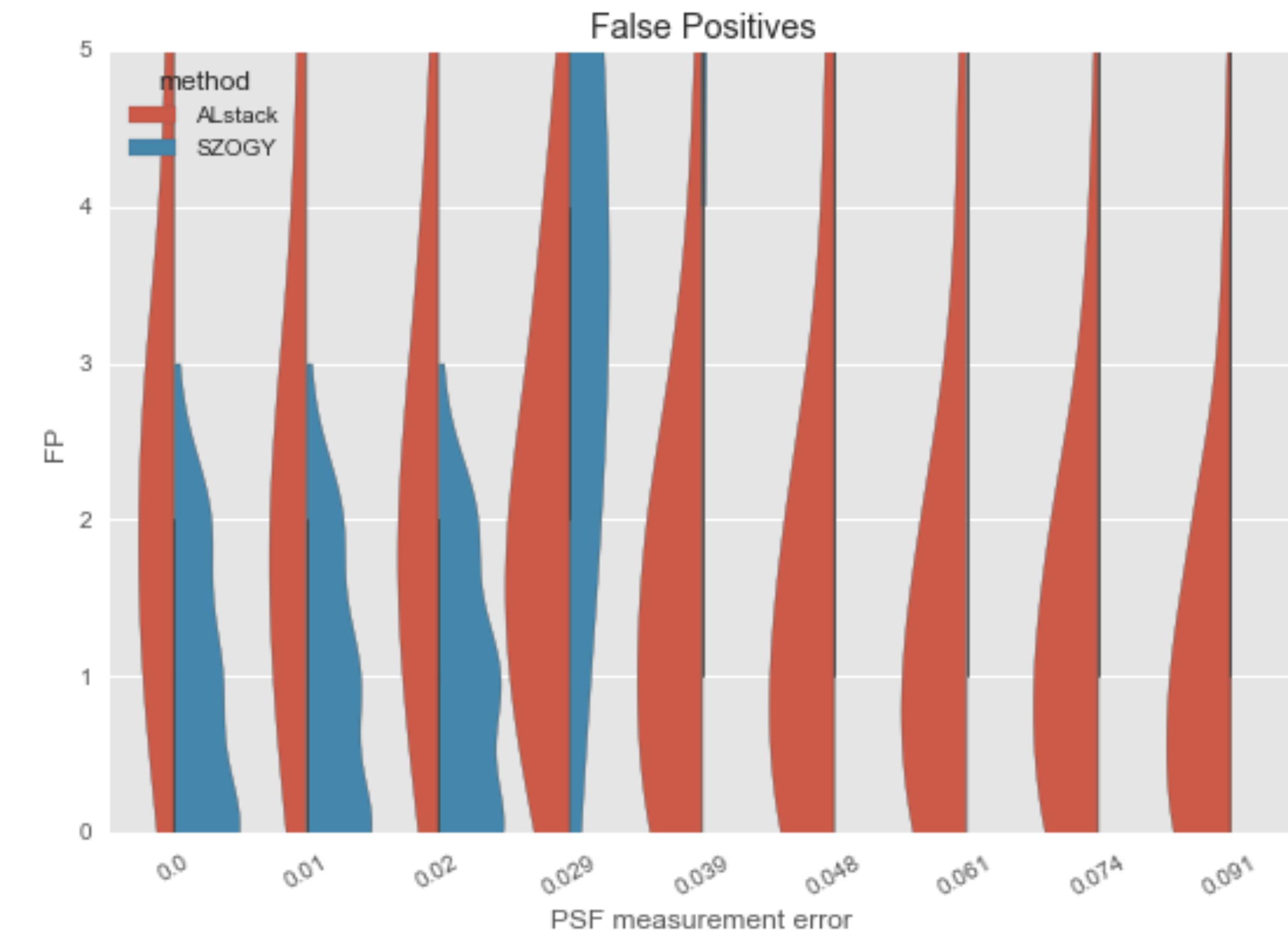
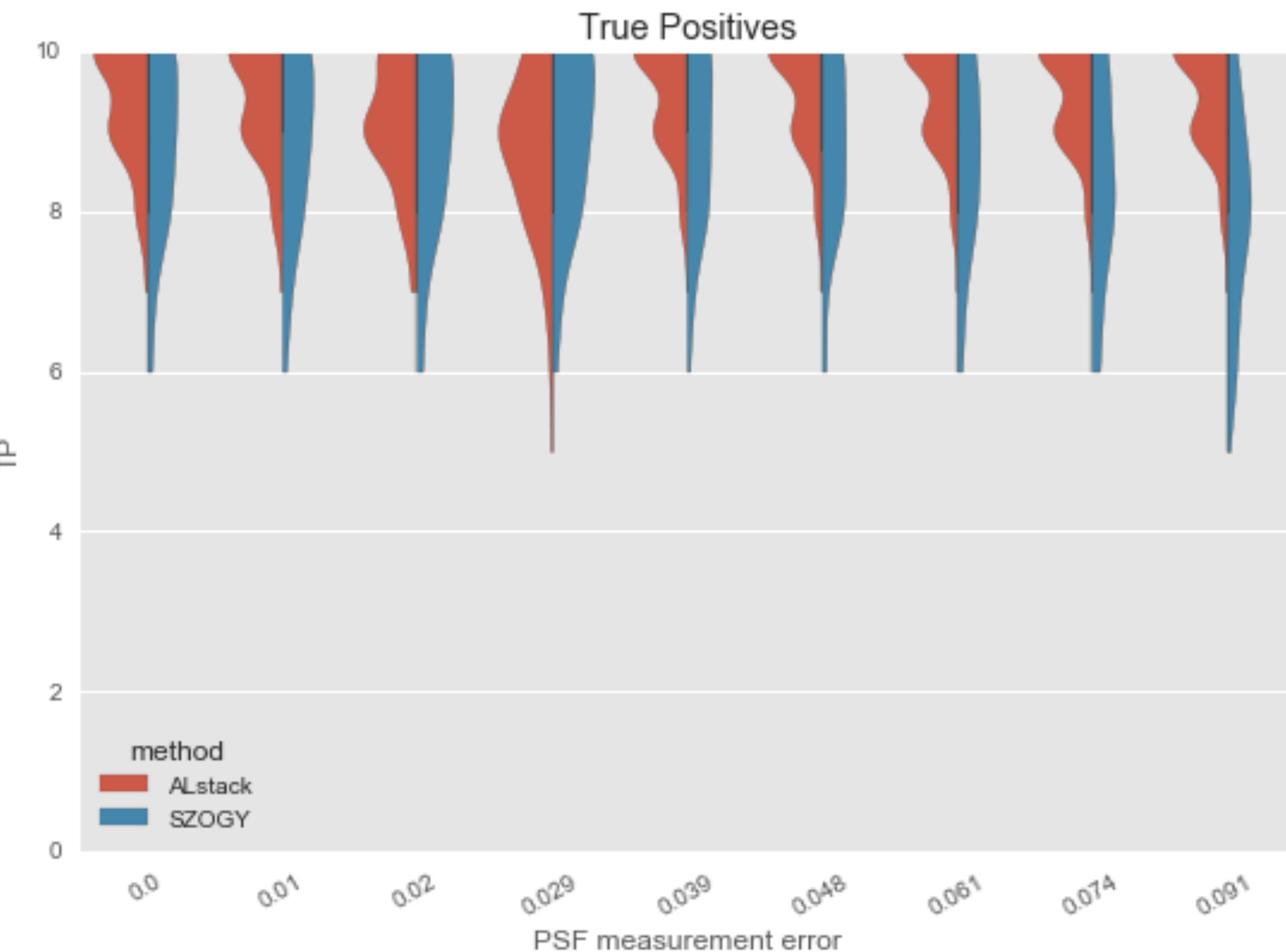
PSF Measurement in LSST Stack



Template: 0.75'' FWHM

Science: 1.04'' FWHM

How can we “break” ZOGY?



Detection rate as a function of PSF mis-estimation

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.