DM IN-DEPTH: LEVEL 1

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LSST2016 PROJECT AND COMMUNITY WORKSHOP
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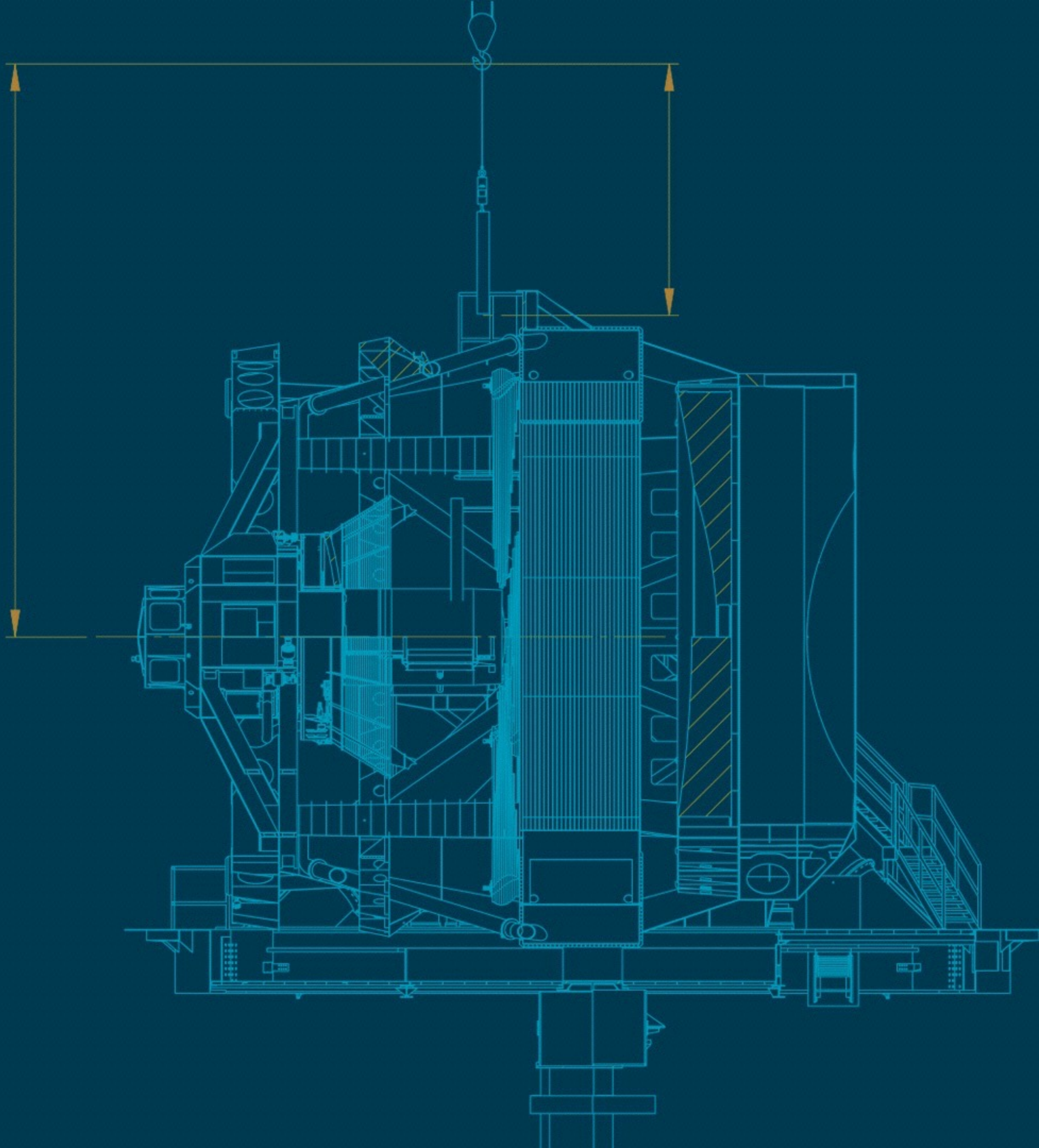
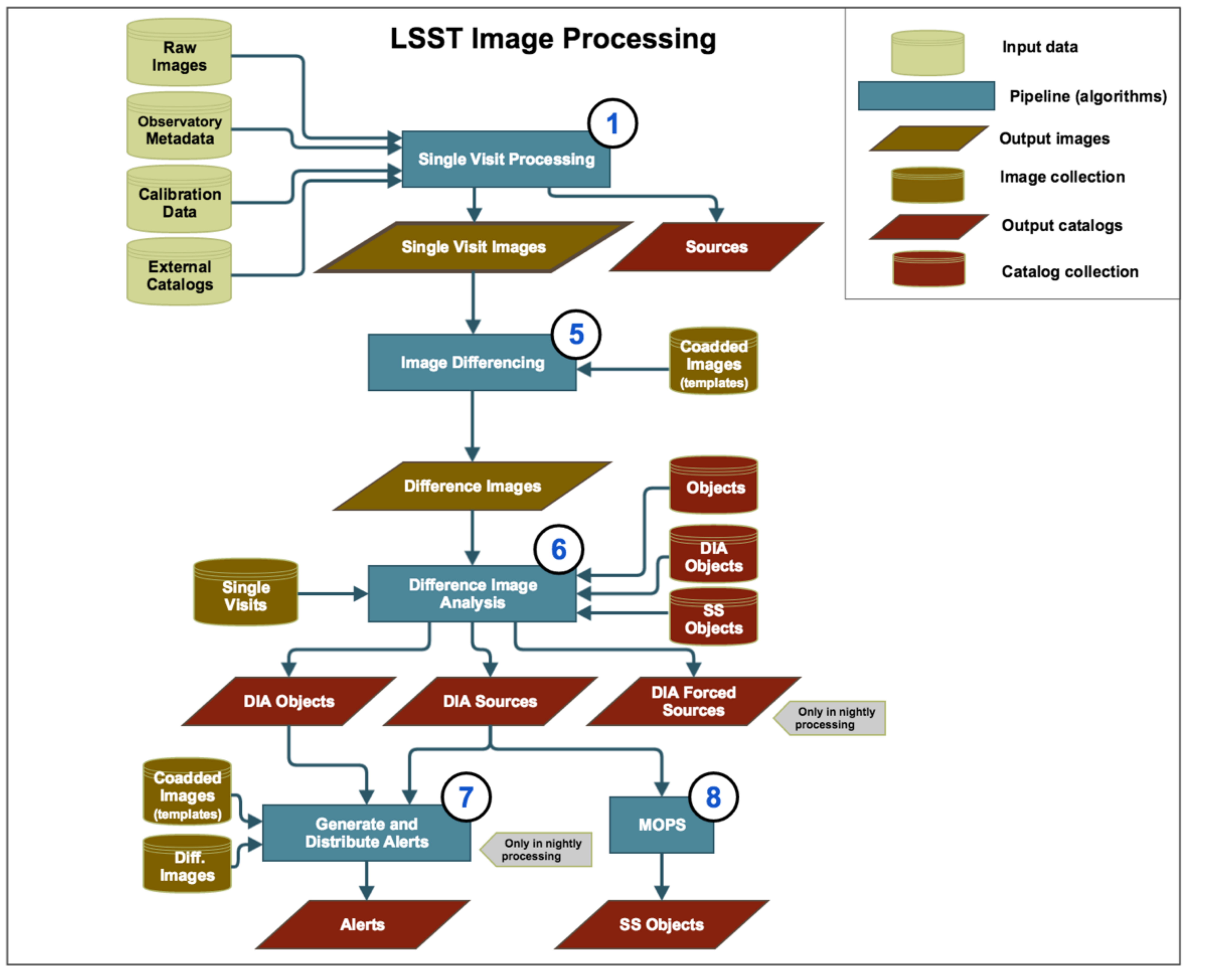


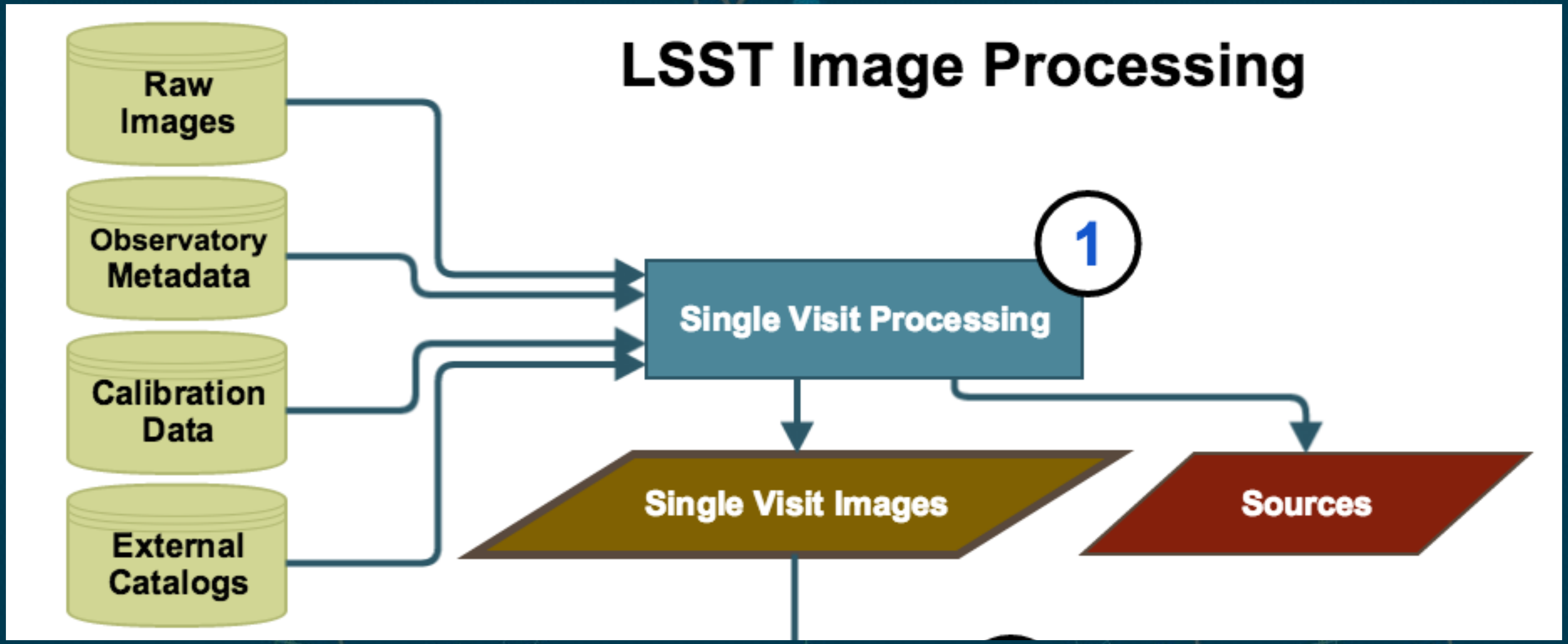
Level 1: Nightly Processing

- Anything that changes by >5 sigma is an DIA Source
  (DIA = Difference Image Analysis)

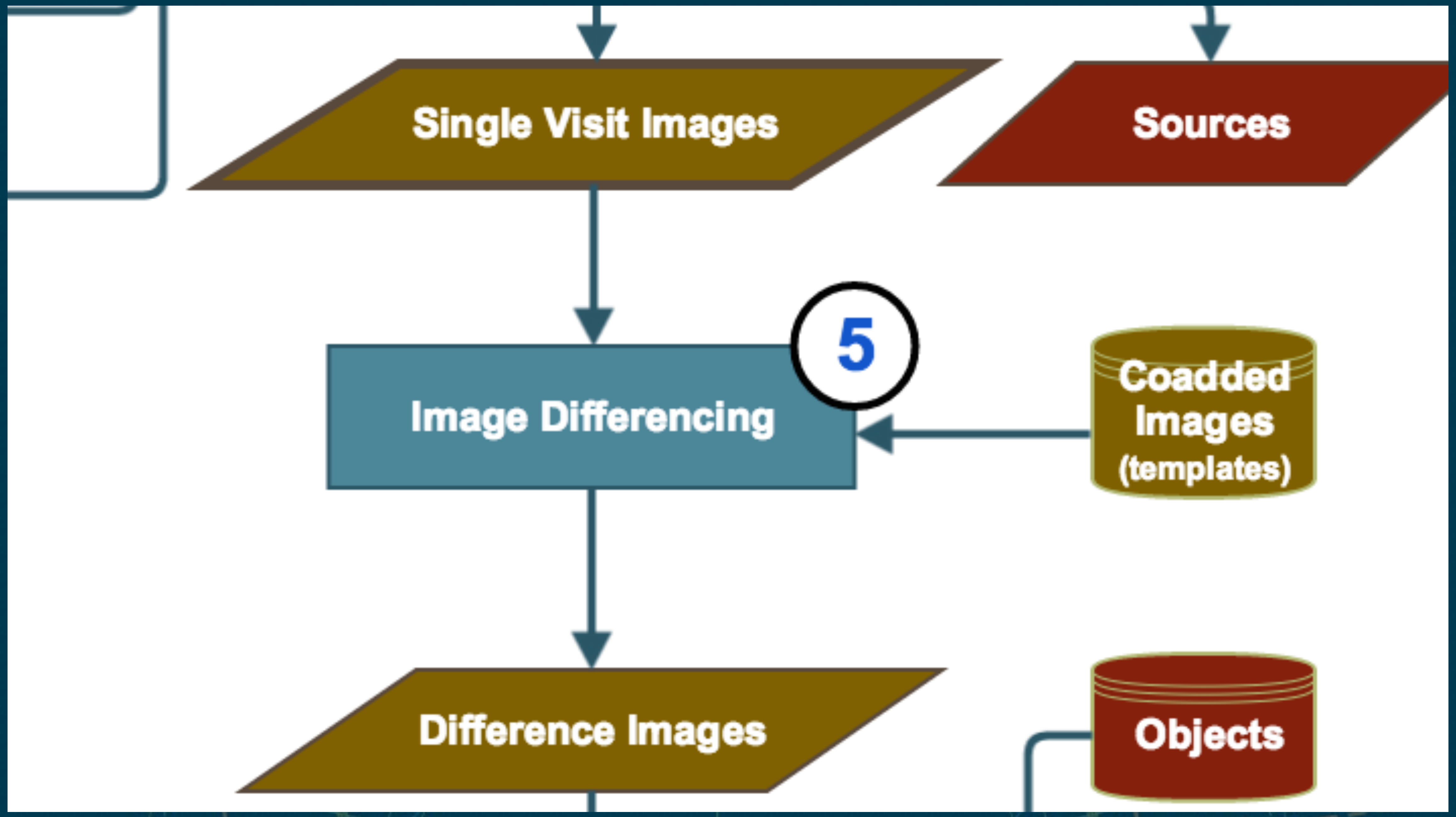
- We will find it, measure it, crossmatch it, and deliver it as an alert to the brokers within 60 seconds of shutter close


LSST Image Processing
Raw Images
Observatory Metadata
Calibration Data
External Catalogs
Single Visit Processing
1
Single Visit Images
Sources
Image Differencing
5
Coadded Images (templates)
Difference Images
Objects
DIA Objects
SS Objects
Single Visits
Difference Image Analysis
6
DIA Objects
DIA Sources
DIA Forced Sources
Only in nightly processing
Coadded Images (templates)
Diff. Images
Generate and Distribute Alerts
7
Only in nightly processing
MOPS
8
Alerts
SS Objects
Input data
Pipeline (algorithms)
Output images
Image collection
Output catalogs
Catalog collection

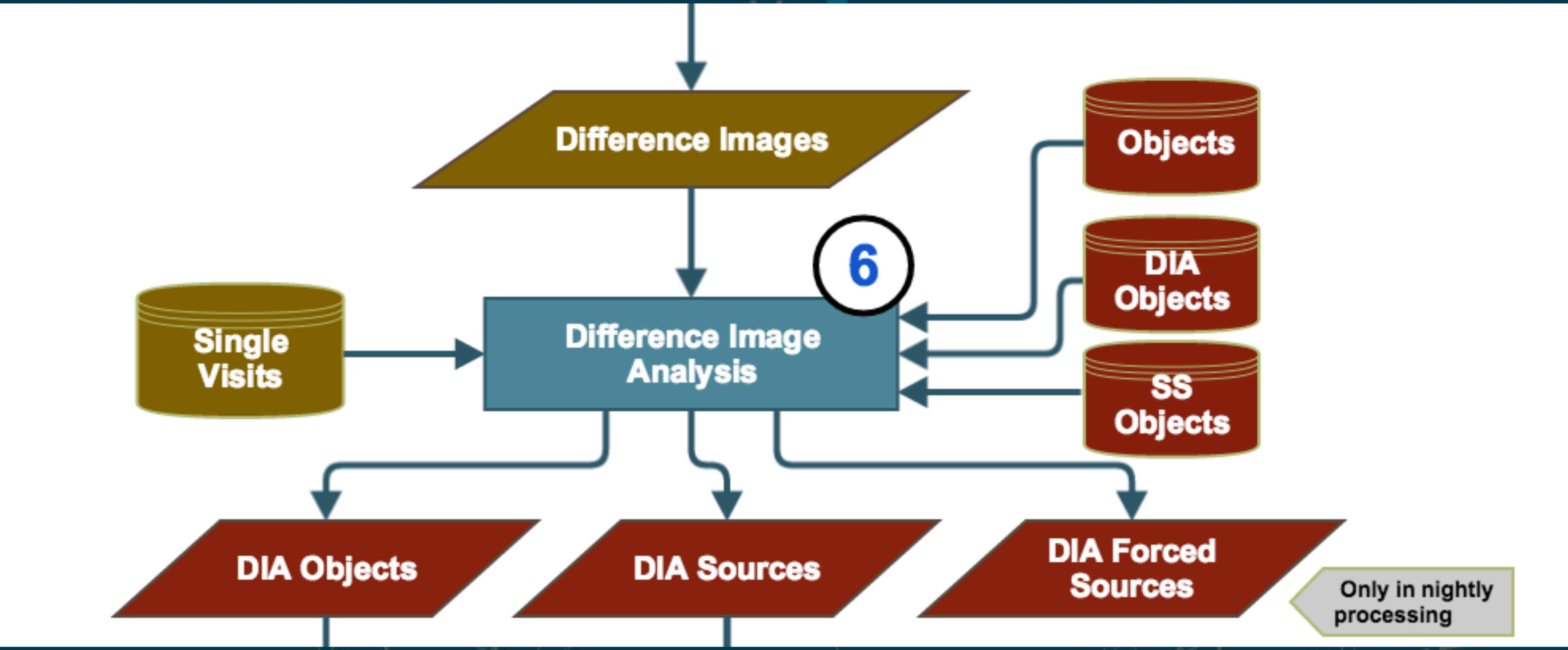
- Single visit processing
- Primarily internal — these are not the science measurements you want!
- PSF determination, astrometric and photometric calibration



- Image differencing: core algorithmic component
- Alard-Lupton algorithm, builds a convolution kernel to match the PSF of the template to the PSF of the science image
- More discussion about this later in the talk



- Difference Image Analysis:
- Everything that changes by >5 sigma creates a new DIA Source. With those detections, we must:
  - Measure DIA Sources
  - Associate with DIA Objects or known Solar System objects
  - Force-photometer previous DIA Objects
- All sent to alert generation, next talk.



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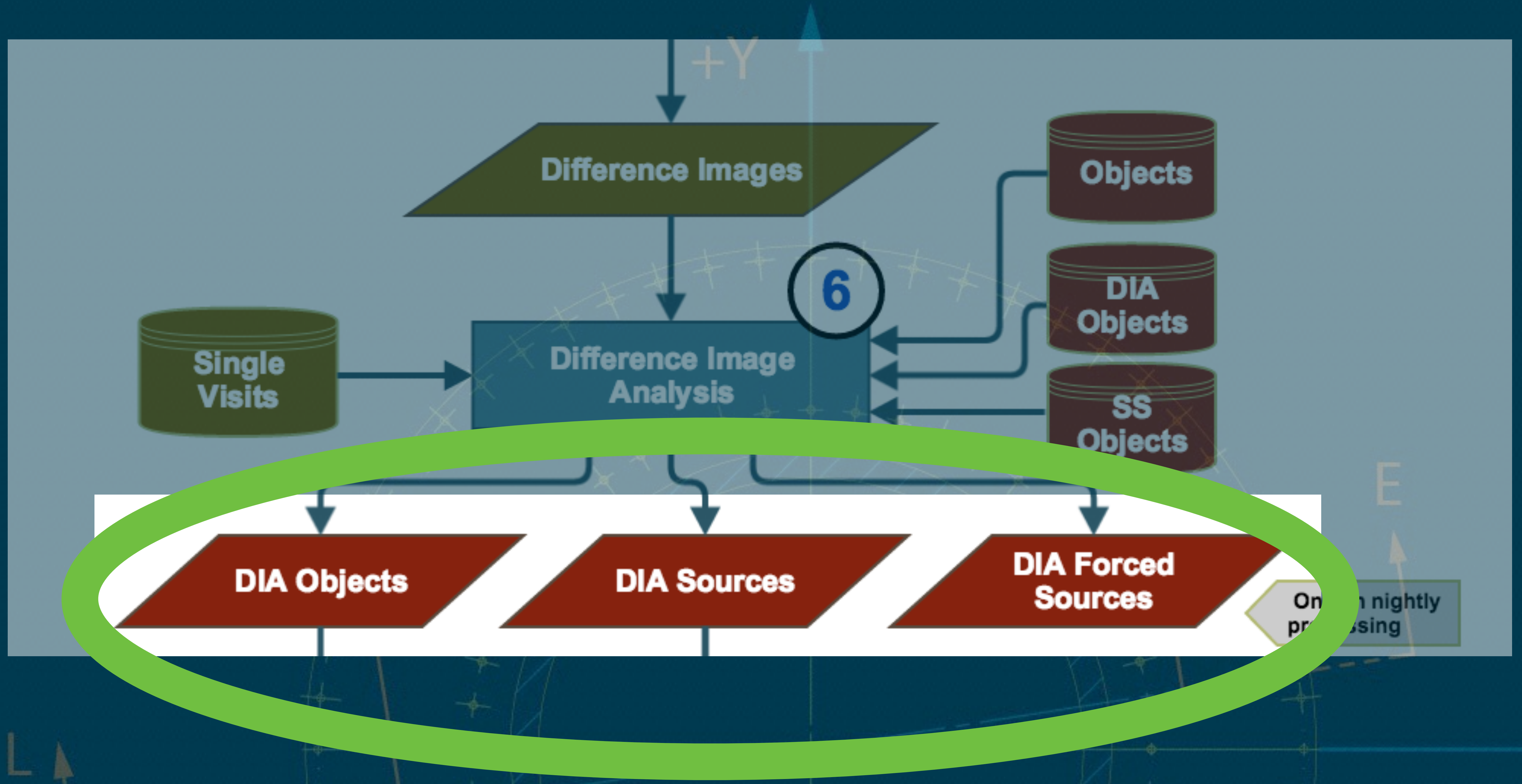
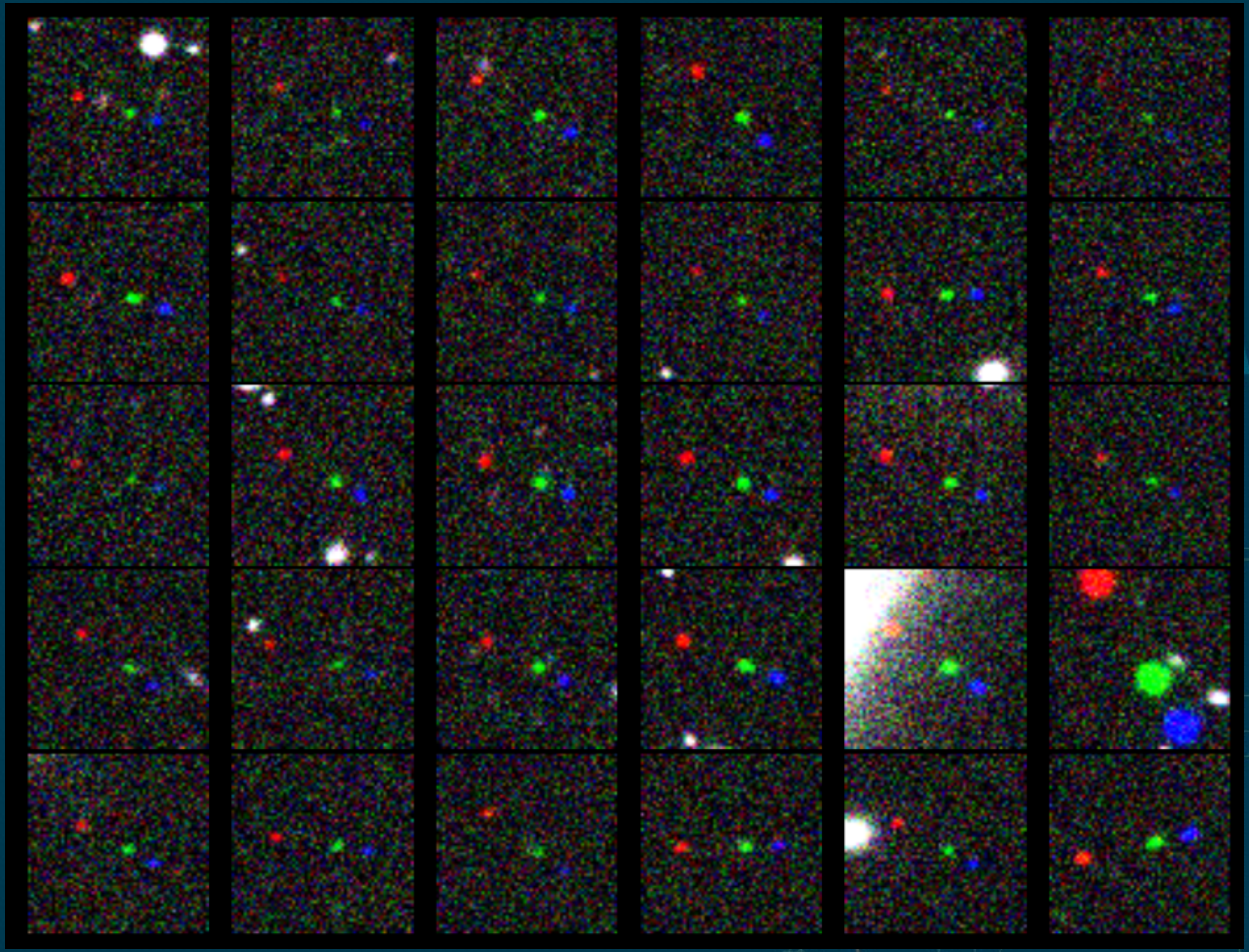


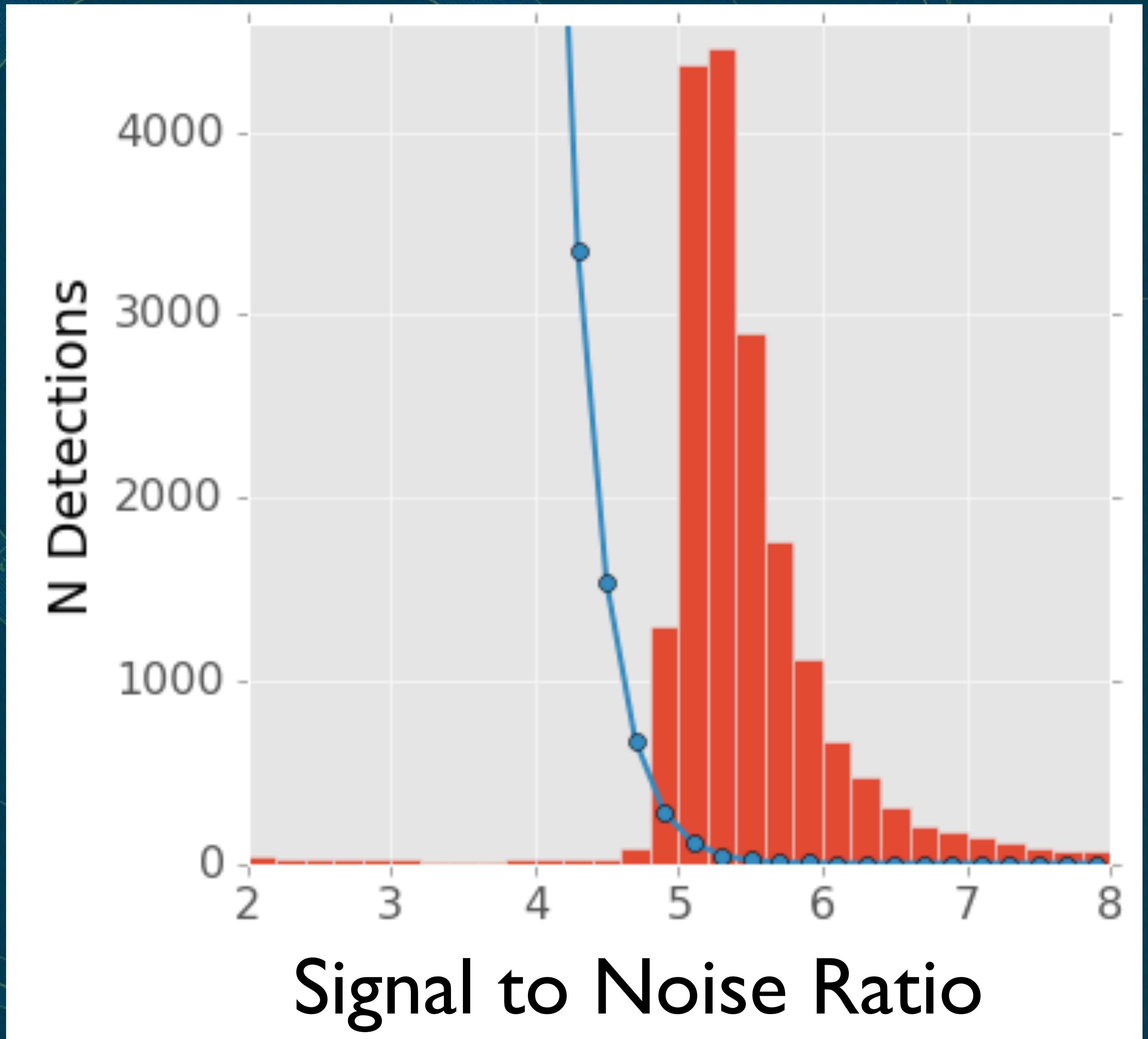


Exercising Level 1

- Every image differencing survey has to fight false positives
- PS1 reported raw rates of ~8000/sq deg, DES 10s of thousands/sq deg
- We know what the distribution from Gaussian random noise looks like, where are the rest coming from?
- Need to test the LSST stack to know how to tackle this problem

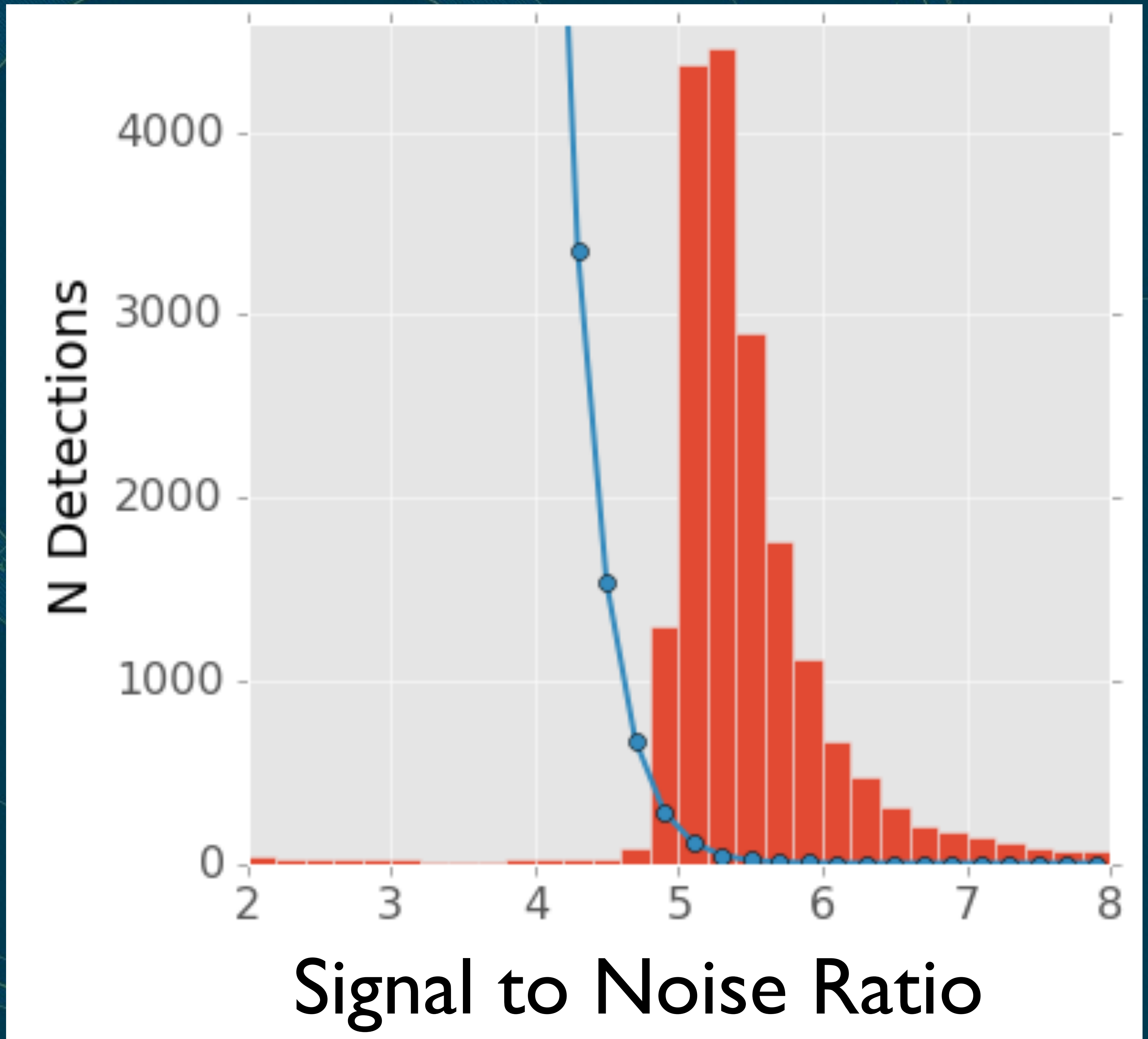
- Began actively exercising the Level 1 pipeline over the last year
- Publicly available DECam images -> single frame processing -> image differencing -> force photometry -> database -> MOPS tracklets.
- Not just a technical demo, goal is to evaluate scientific performance

Gaussian Expectation | Observed Detections

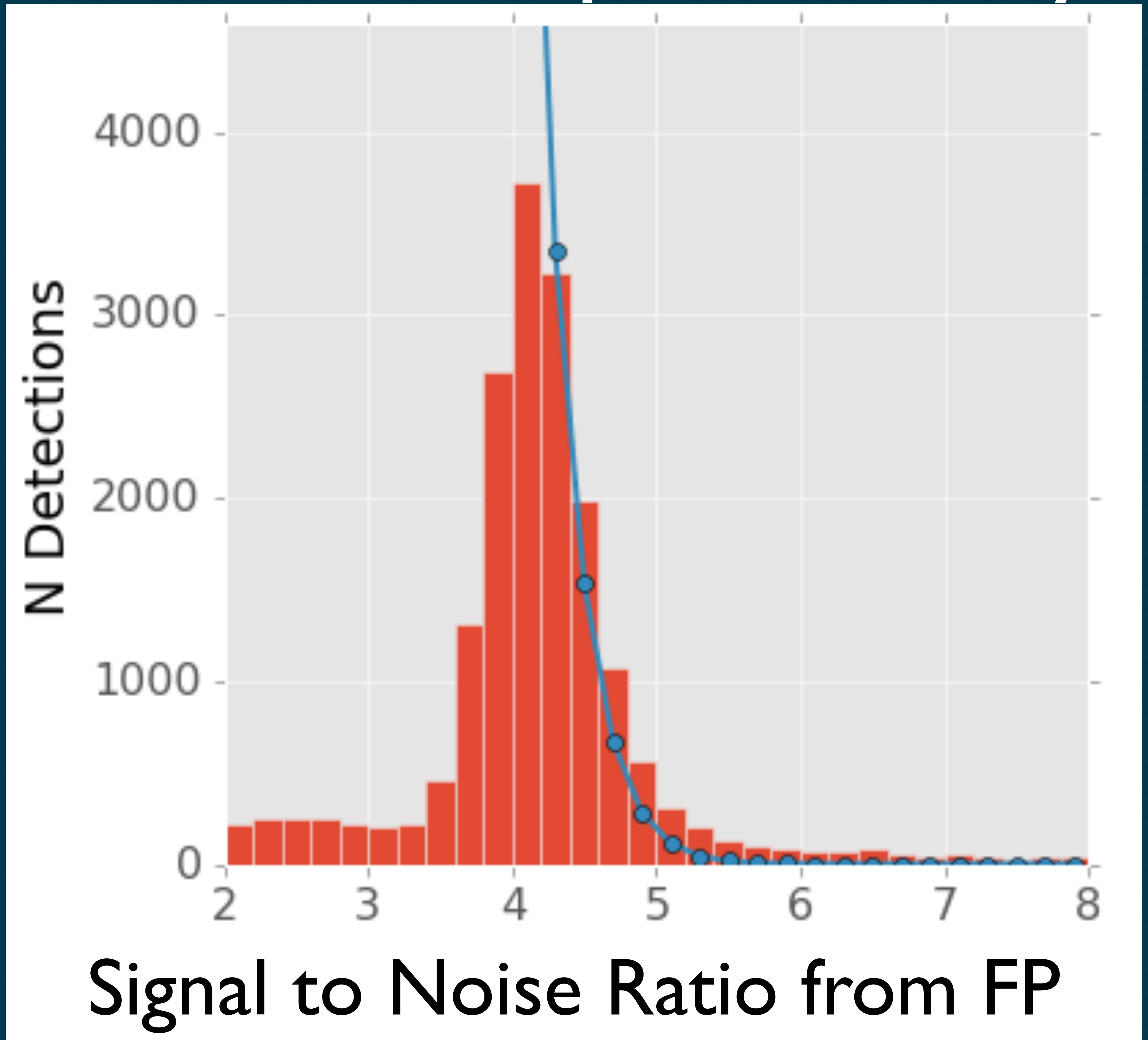


- We expect a steep rise in detections below SNR of 5 (if we set our threshold that low)
- We see this steep rise appear closer to SNR of 6 —*this comes from a misestimation of the image noise*

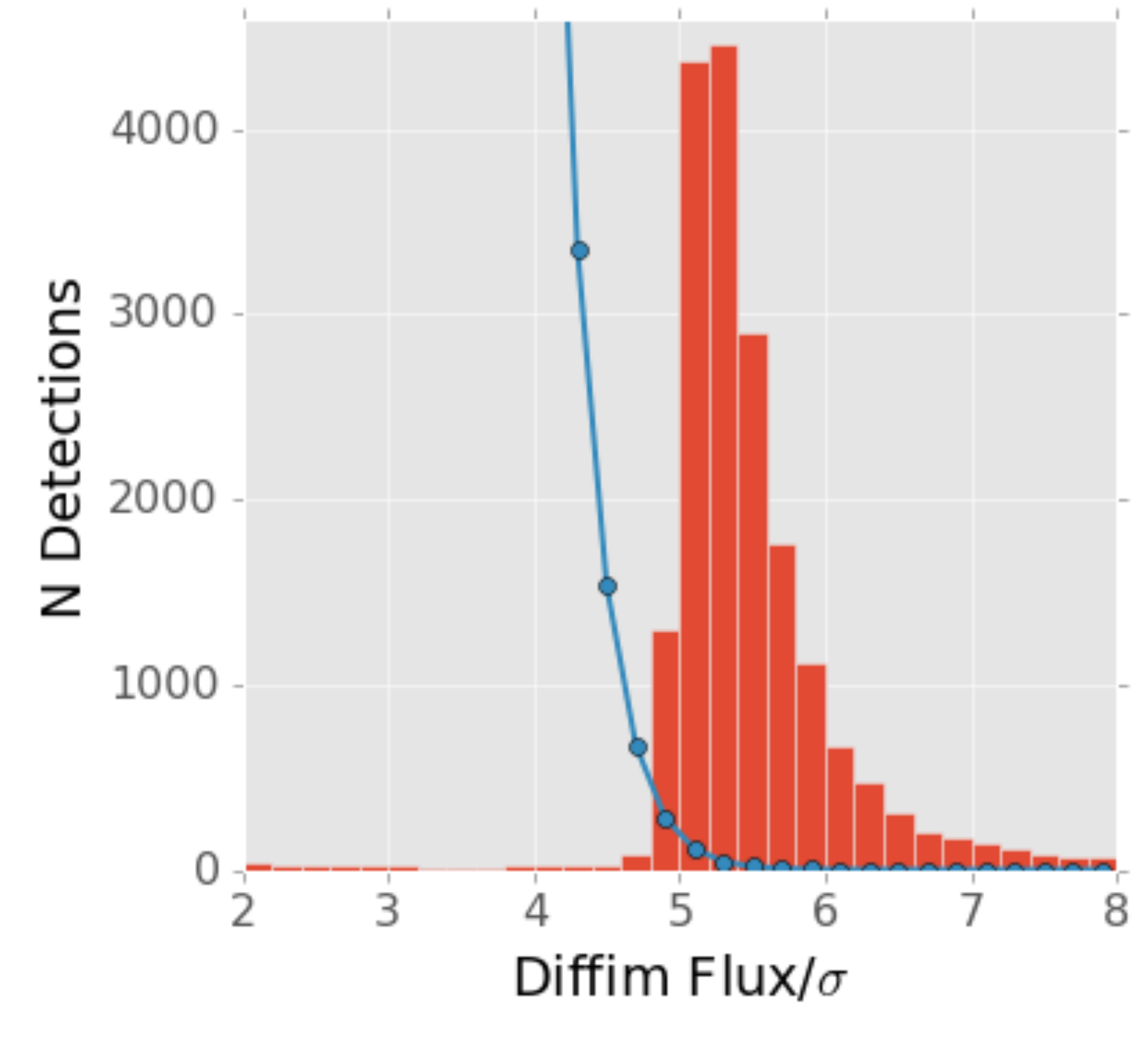
Gaussian Expectation   Observed Detections

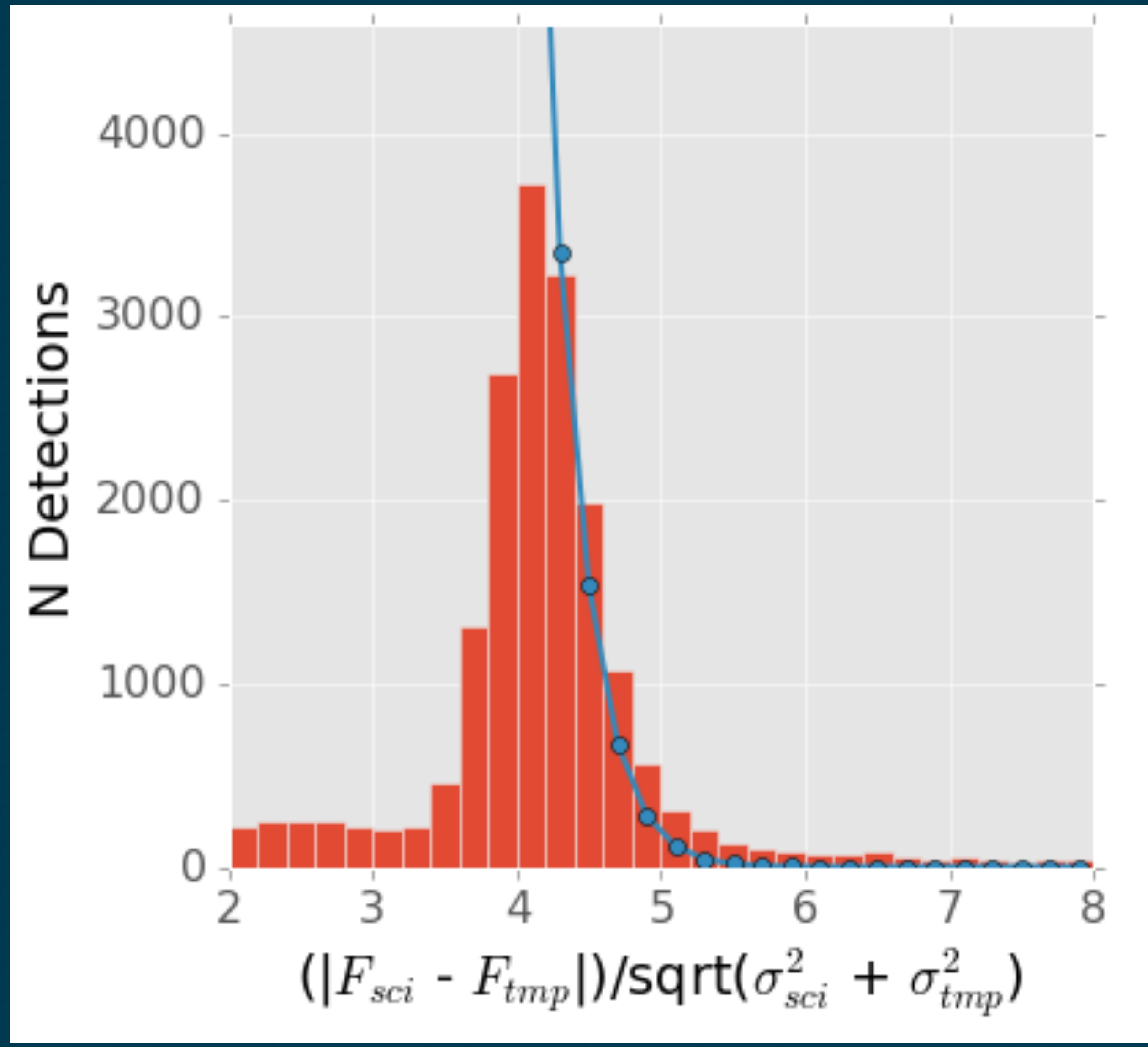


Properly estimated noise with forced photometry



- The cause is correlated noise due to PSF matching.
- Convolving the template to match the PSF of the science image reduces the *per-pixel noise* (essentially a smoothing).
- The original noise is "still there", but it is spread between neighboring pixels on PSF-size scales. Hidden in the off-diagonal elements of the covariance matrix.
- Standard photometry software ignores this, misreports SNR.





Full analysis at http://dmtn-006.lsst.io/

- Several possible solutions:
  - Track the covariance matrix, N_{pixels} by N_{pixels}
  - Track all image operations, covariance “on the fly”
  - Convolve with decorrelation kernel, “whiten” the noise

PSF Matching Kernel

Decorrelation Kernel

$$\widehat{D}(k) = \left[\widehat{I}_1(k) - \widehat{\kappa}(k)\widehat{I}_2(k)\right]\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{\sigma_1^2 + \widehat{\kappa}^2(k)\sigma_2^2}}$$

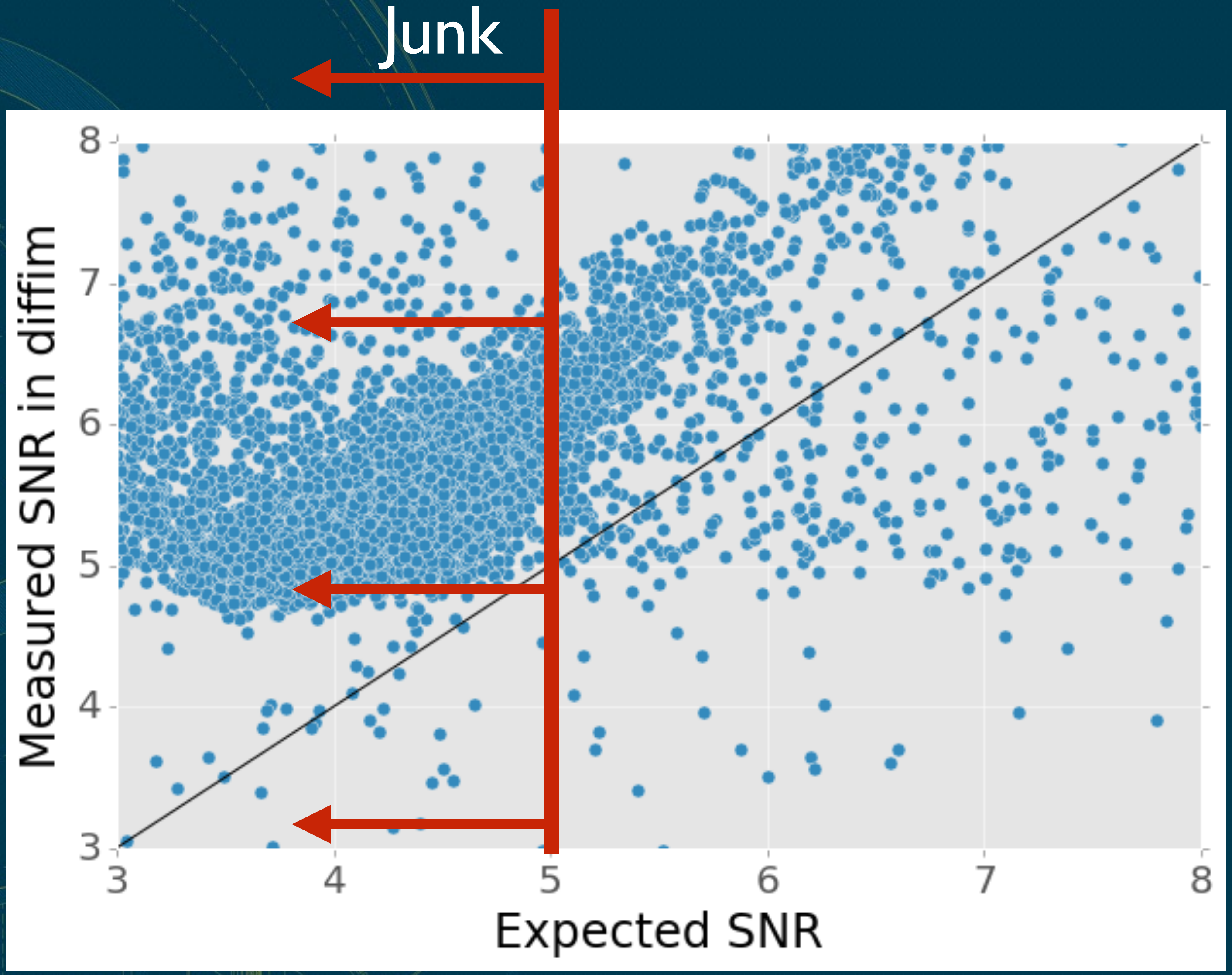
Difference Image

Sci Image

Template Image

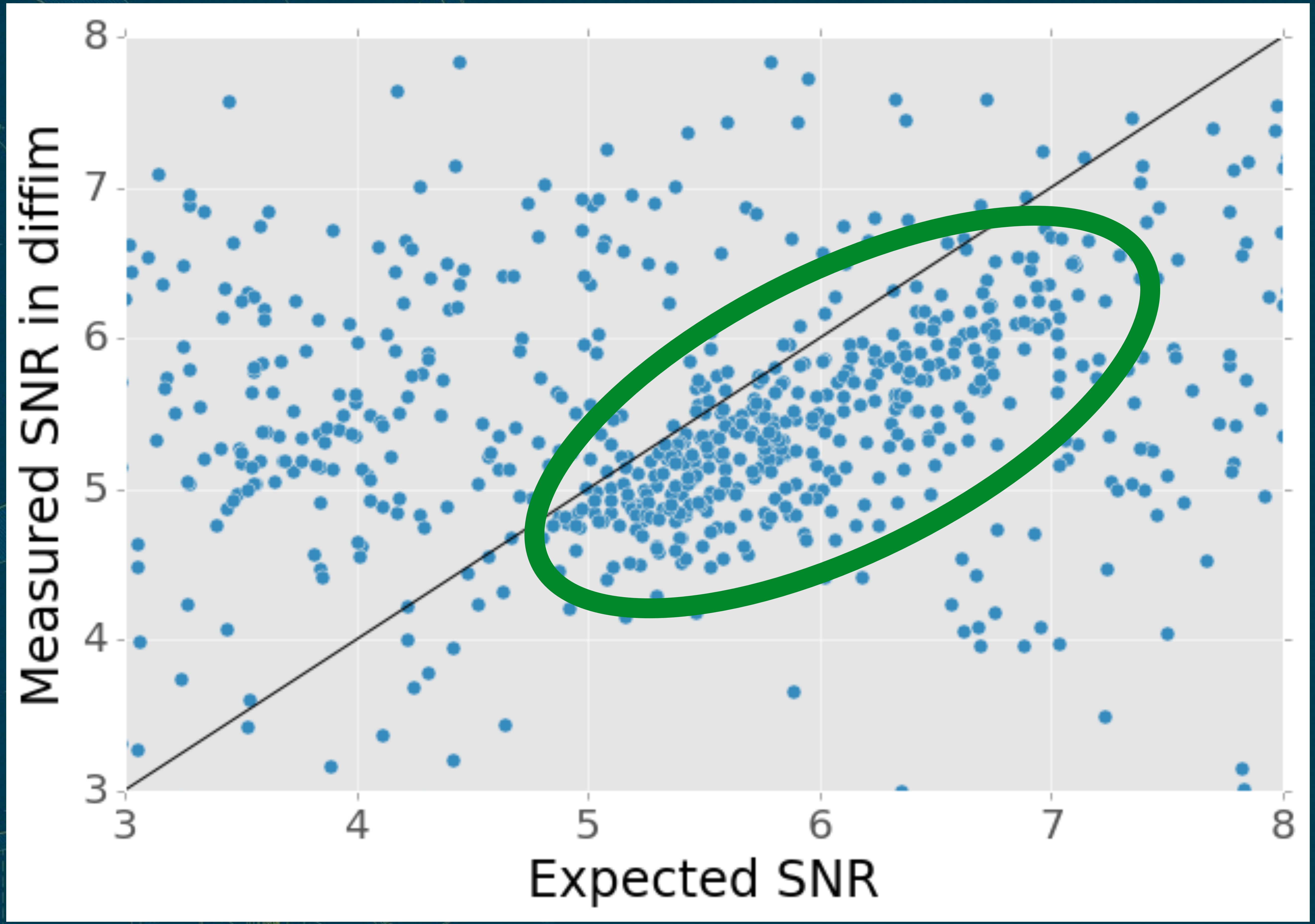
Full details at https://dmtn-021.lsst.io/

Without Decorrelation



Implementation and testing by David Riess, see dmtn-021.lsst.io/

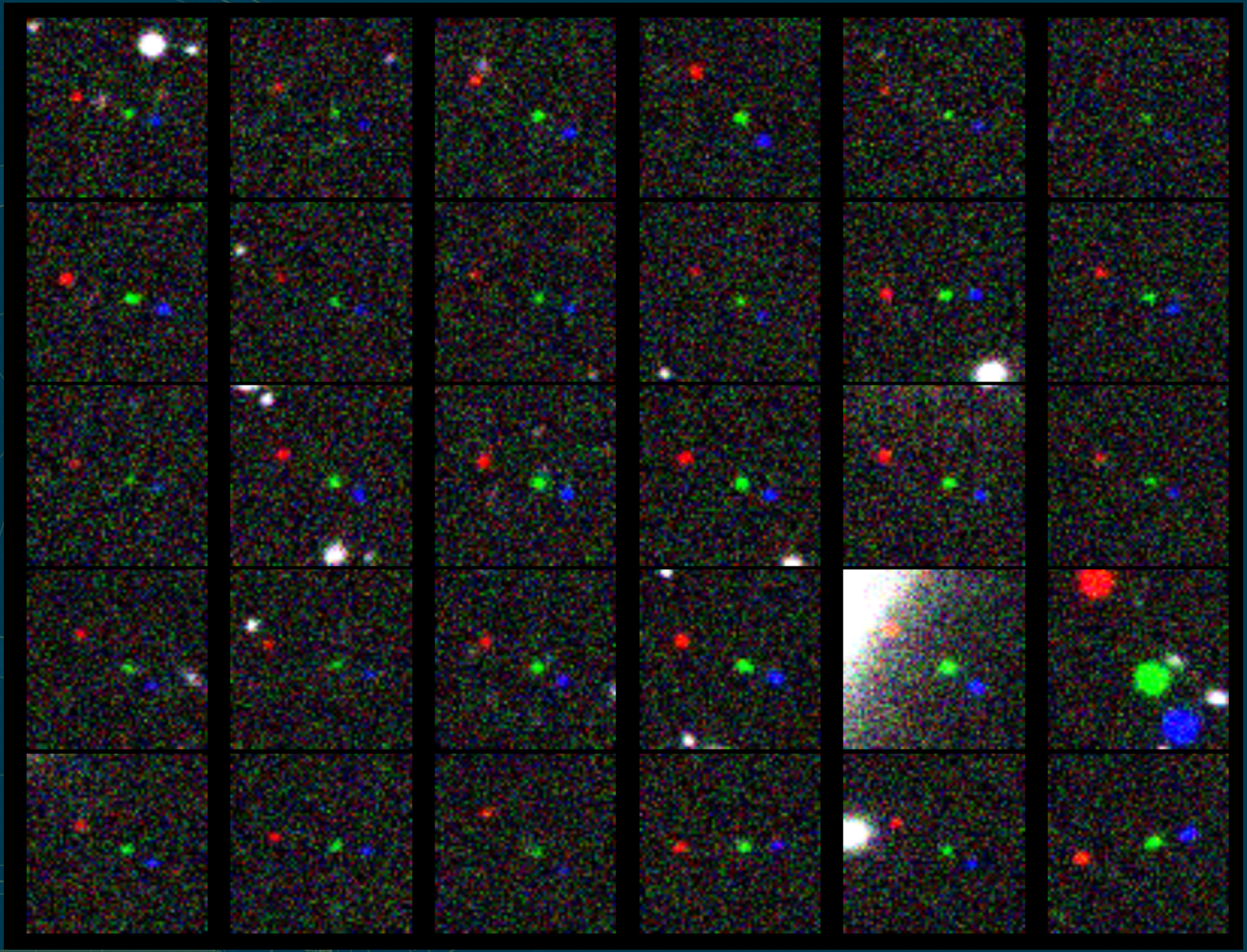
With Decorrelation



Real detections at the right SNR

Implementation and testing by David Riess, see 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. We know MOPS can work at this density, without post-filtering by machine learning algorithms.



Representative sample found by MOPS

150 tracklets with 3 detections in one Decam FoV

RGB: three different epochs, ~10 min separation

Summary

- We have a theoretical understanding of the correlated noise problem and how to fix it.
- This fix has been demonstrated on real data with the LSST stack
- The reduction in false positives is an order of magnitude
- This removes the need for strong post-filtering of detections