Identifying Exoplanets with CSP Filtering and a Forward Model Matched Filter

Jan 7, 2020
AAS #342.04

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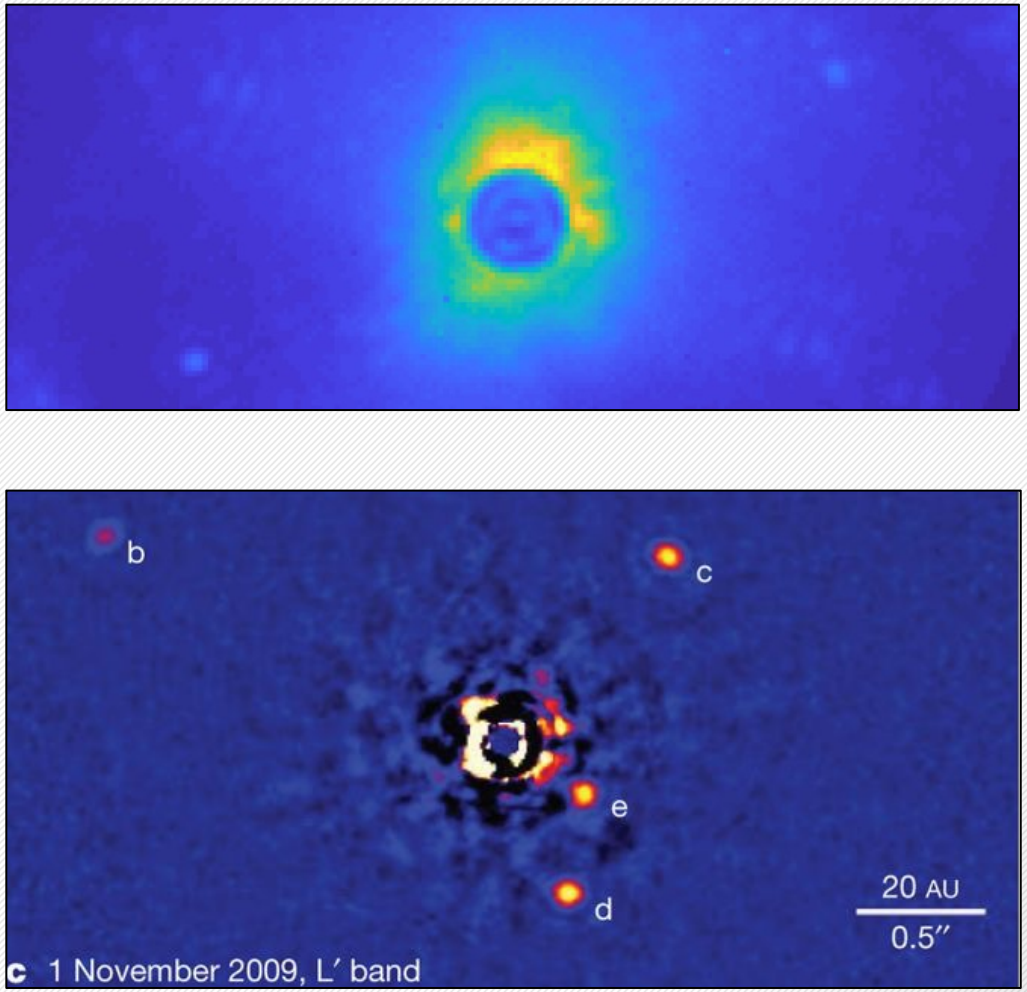
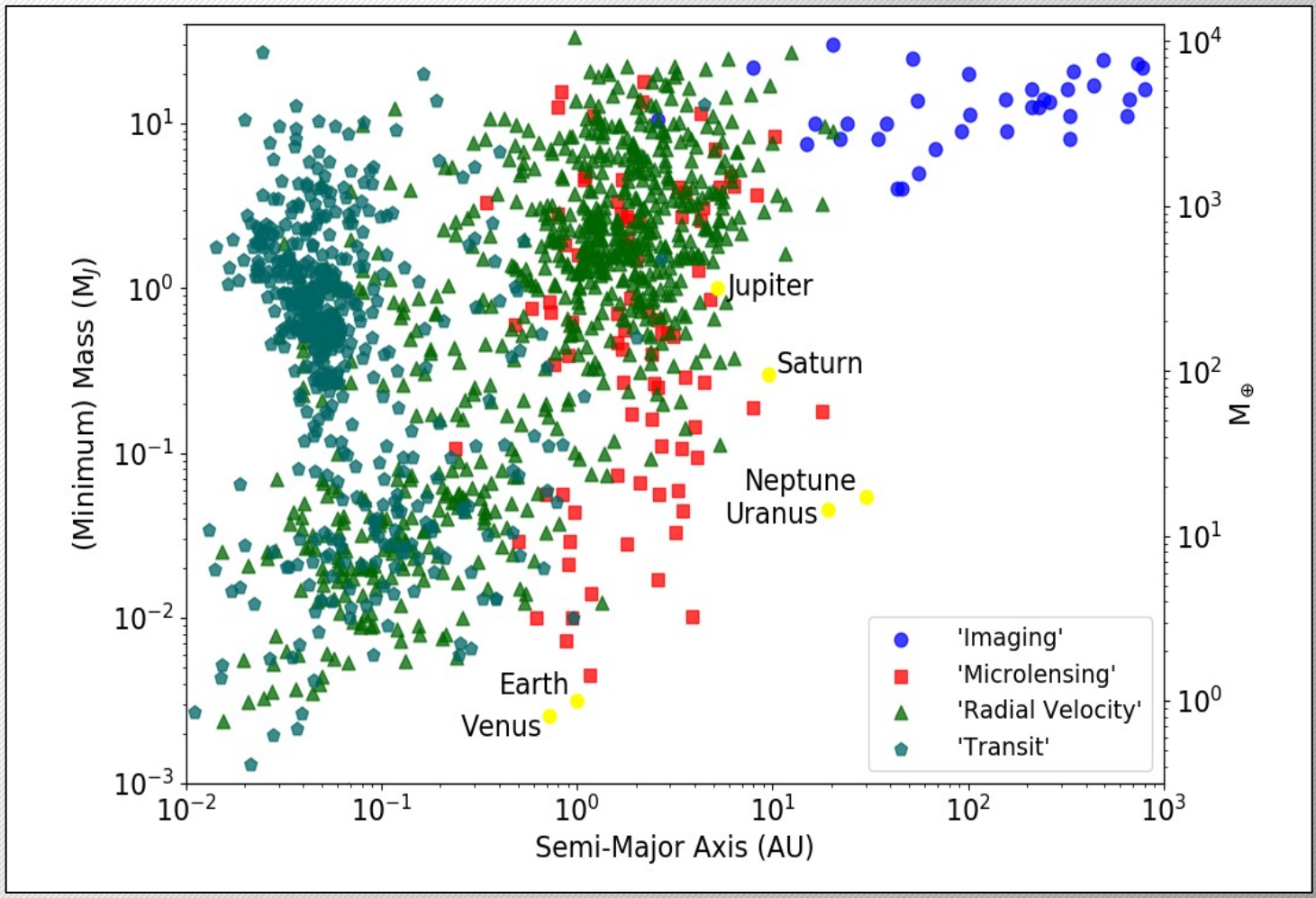
Direct Imaging

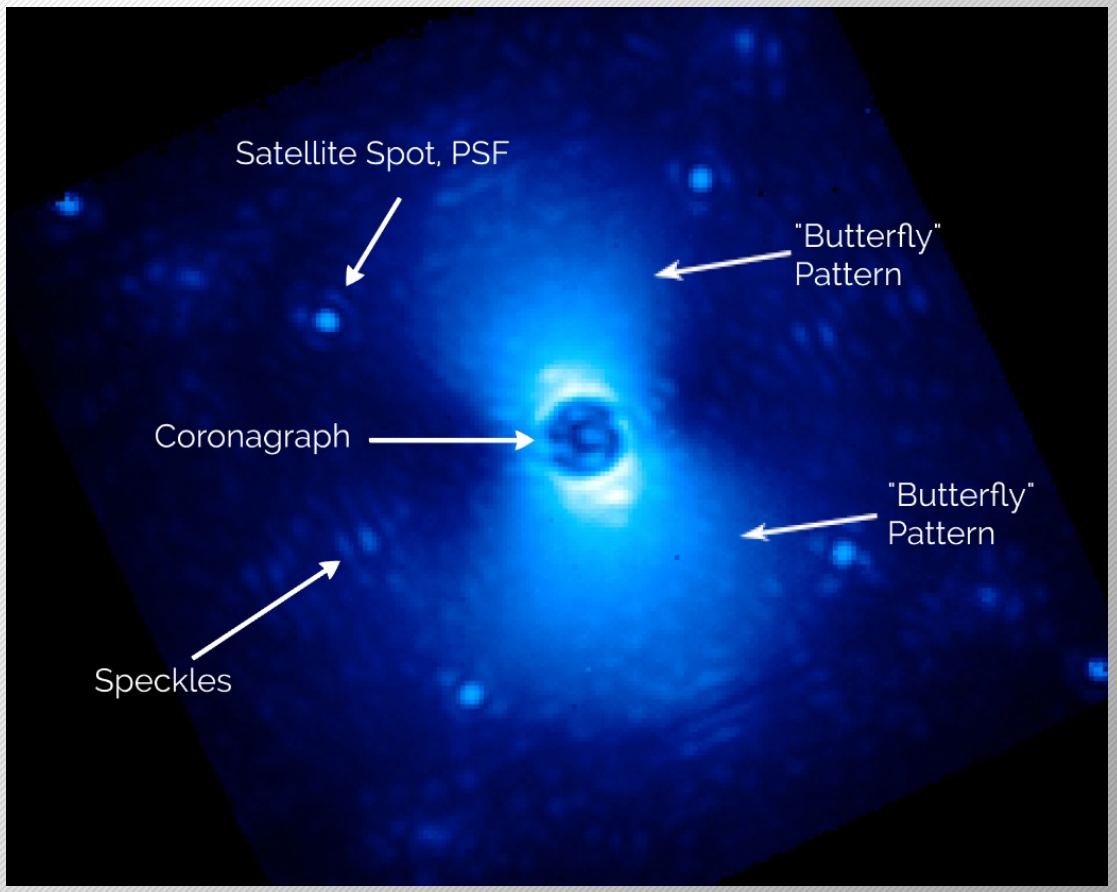


Marois, 2010



Noisy Images

University of Texas

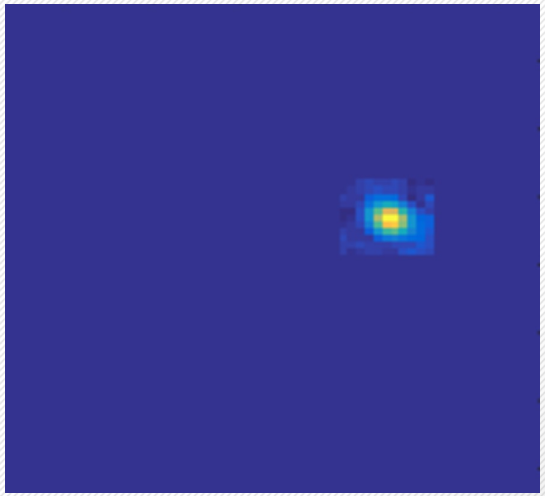


Perrin, 2014

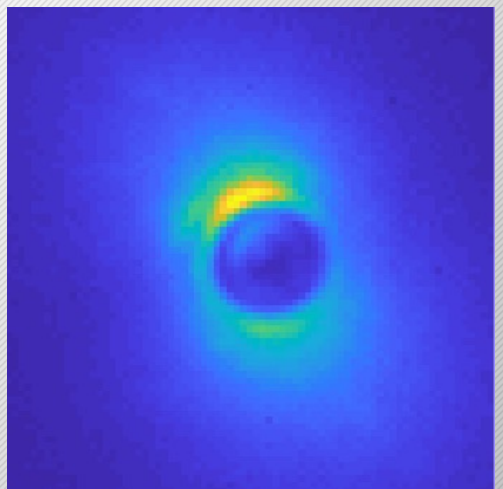
Data Used

- Gemini Planet Imager
- Near Infrared
- Like Observations:
  - H-Band
  - Star Magnitude
  - AO Performance

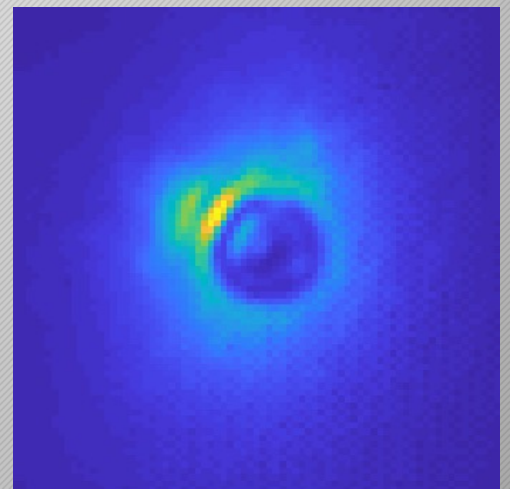
Injected Planet Sample



HD 14706

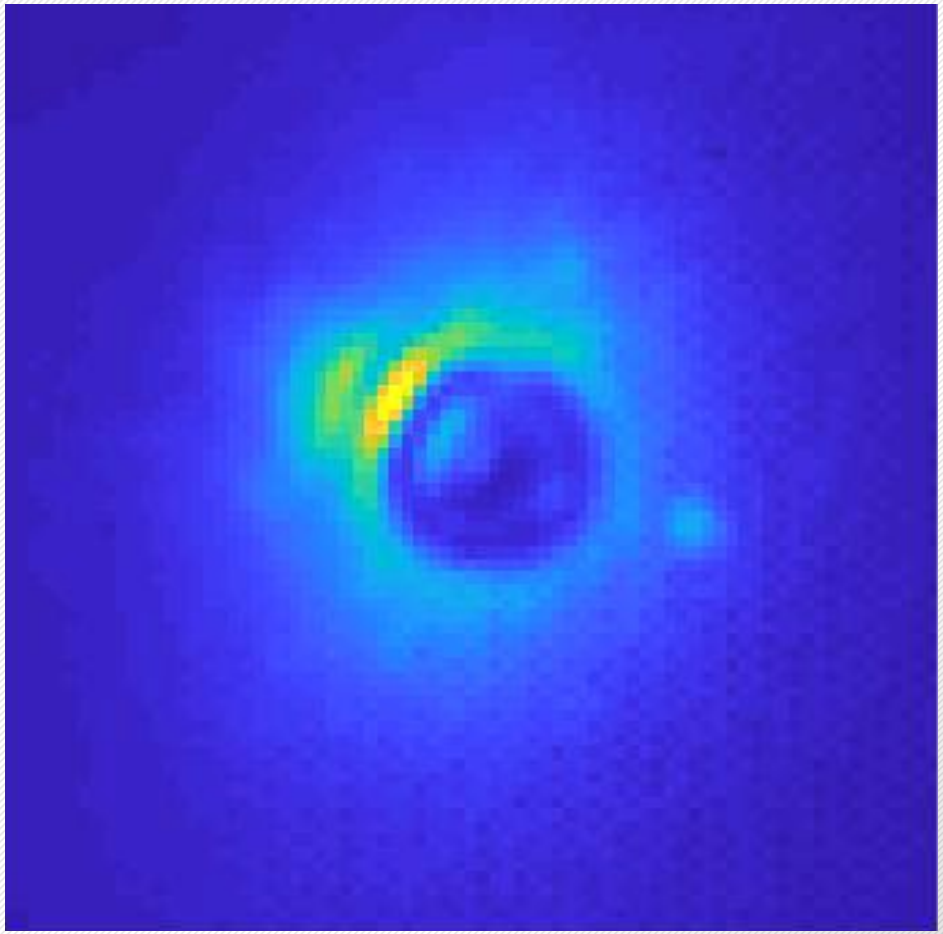


B Pictoris

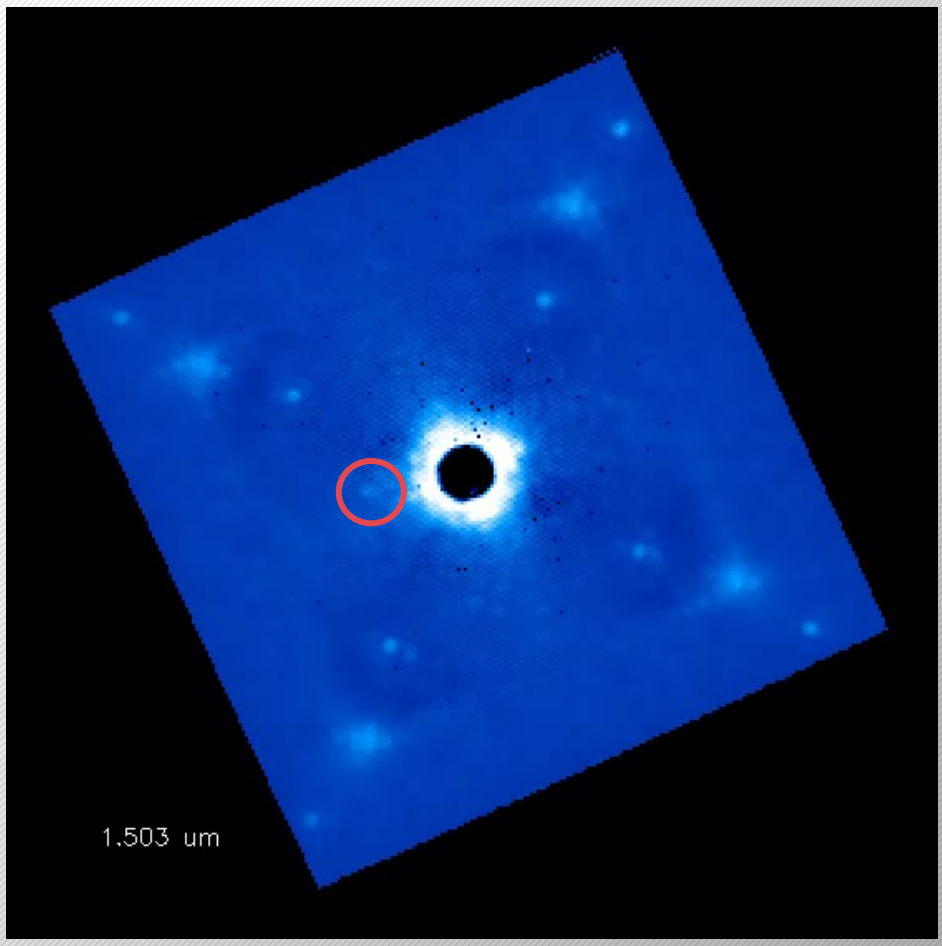


Spatial Diversity of the Planet Signal

Temporal



Wavelength



PCA vs CSP

Principal Component Analysis

$$\arg\max_{\mathbf{w}} \left\|\mathbf{X}^T\mathbf{w}\right\|^2 \quad \text{s.t.} \quad \|\mathbf{w}\| = 1$$

- Finds direction of maximum variance
- Models the noise
- Subtracts the noise

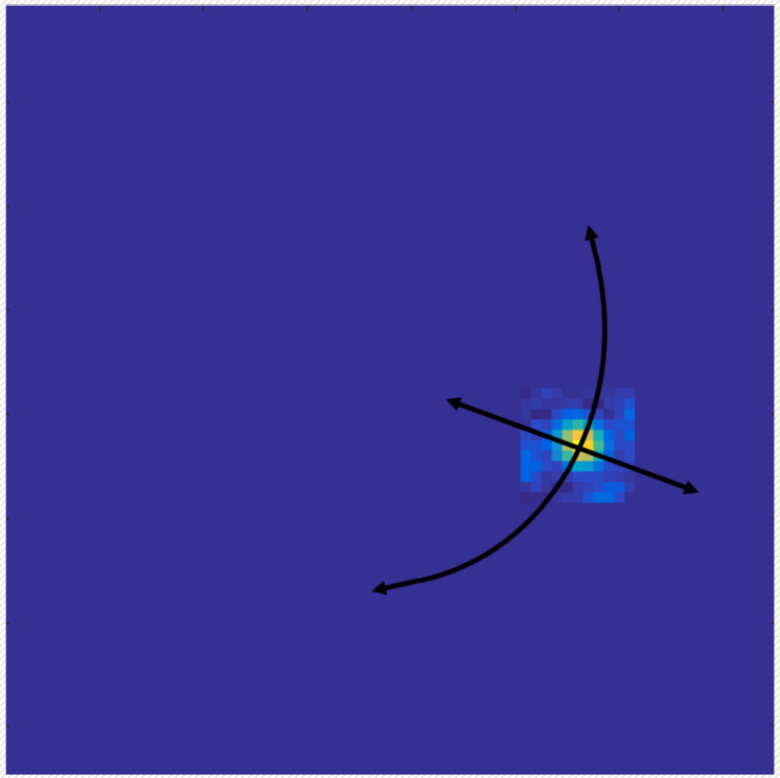
Common Spatial Pattern Filtering

$$\arg\max_{\mathbf{w}} \frac{\left\|\mathbf{X}_1^T\mathbf{w}\right\|^2}{\left\|\mathbf{X}_2^T\mathbf{w}\right\|^2} \quad \text{s.t.} \quad \|\mathbf{w}\| = 1$$

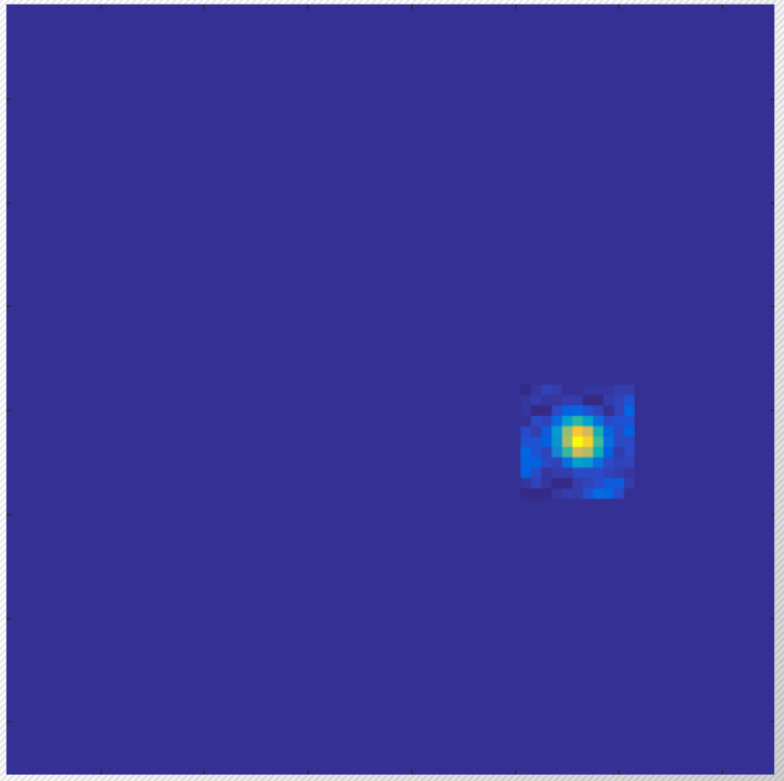
- Finds direction of maximum difference
- Planet should be part of the “difference”
- Models the planet signal

CSP: Designing X_1 and X_2

Dataset 1:

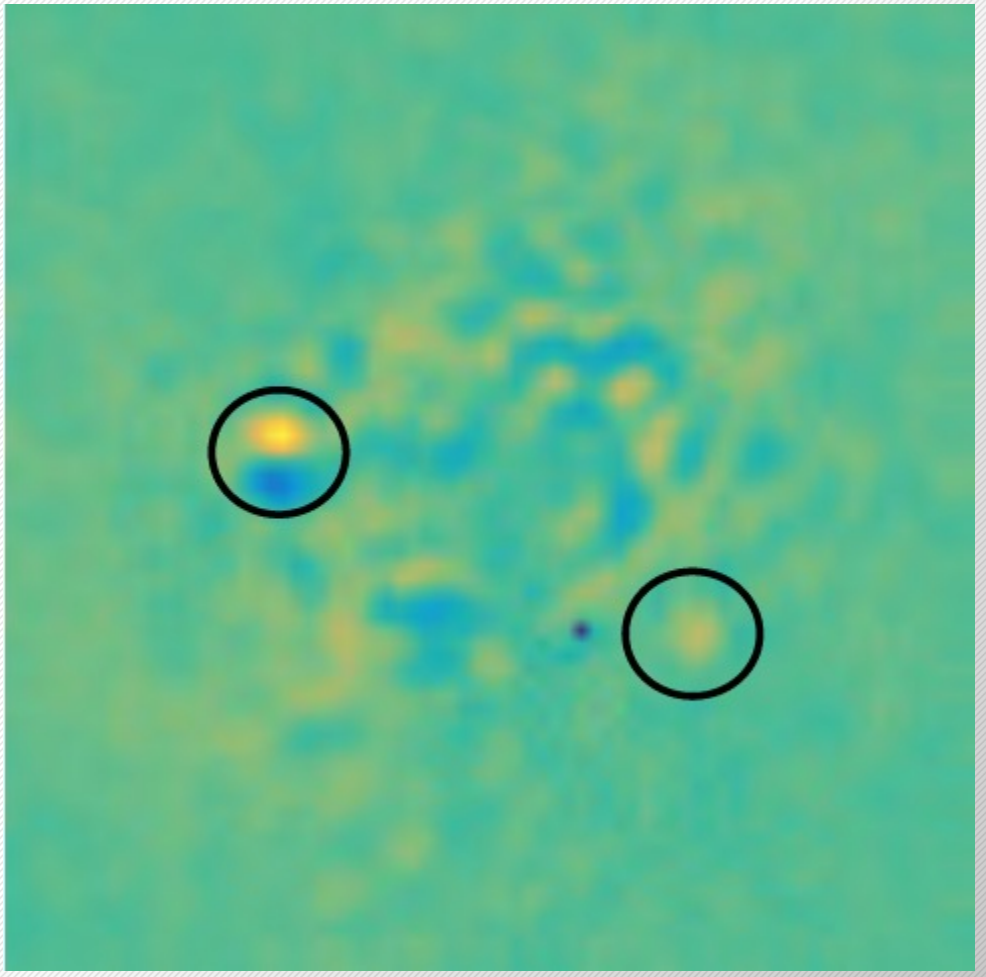


Dataset 2:



$$\arg\max_{\mathbf{w}} \frac{\|\mathbf{X}_1^T\mathbf{w}\|^2}{\|\mathbf{X}_2^T\mathbf{w}\|^2} \quad \text{s.t.} \quad \|\mathbf{w}\| = 1$$

CSP: Processed

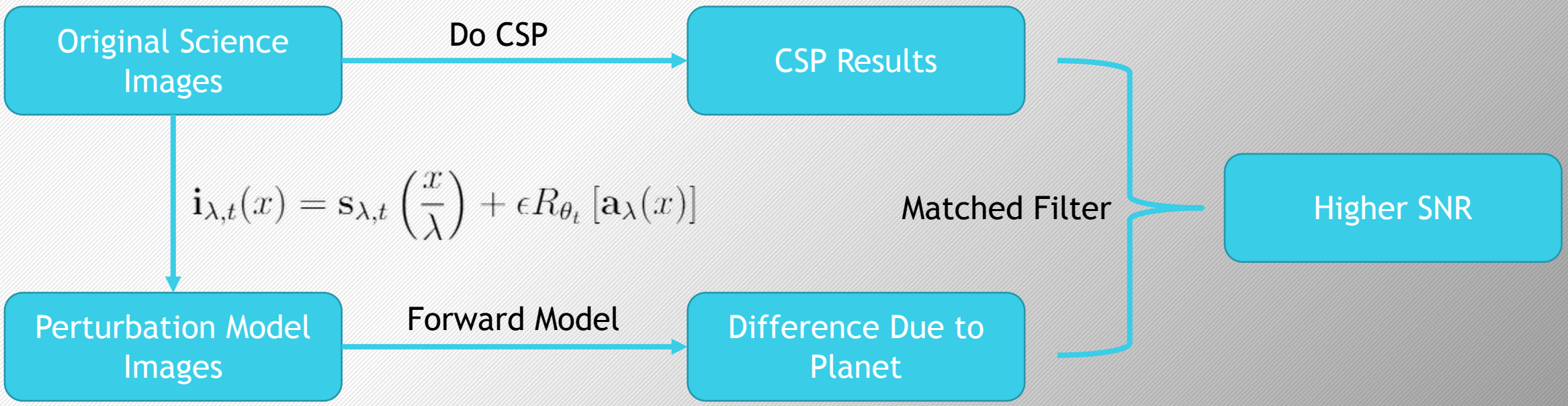


Pretty Lousy

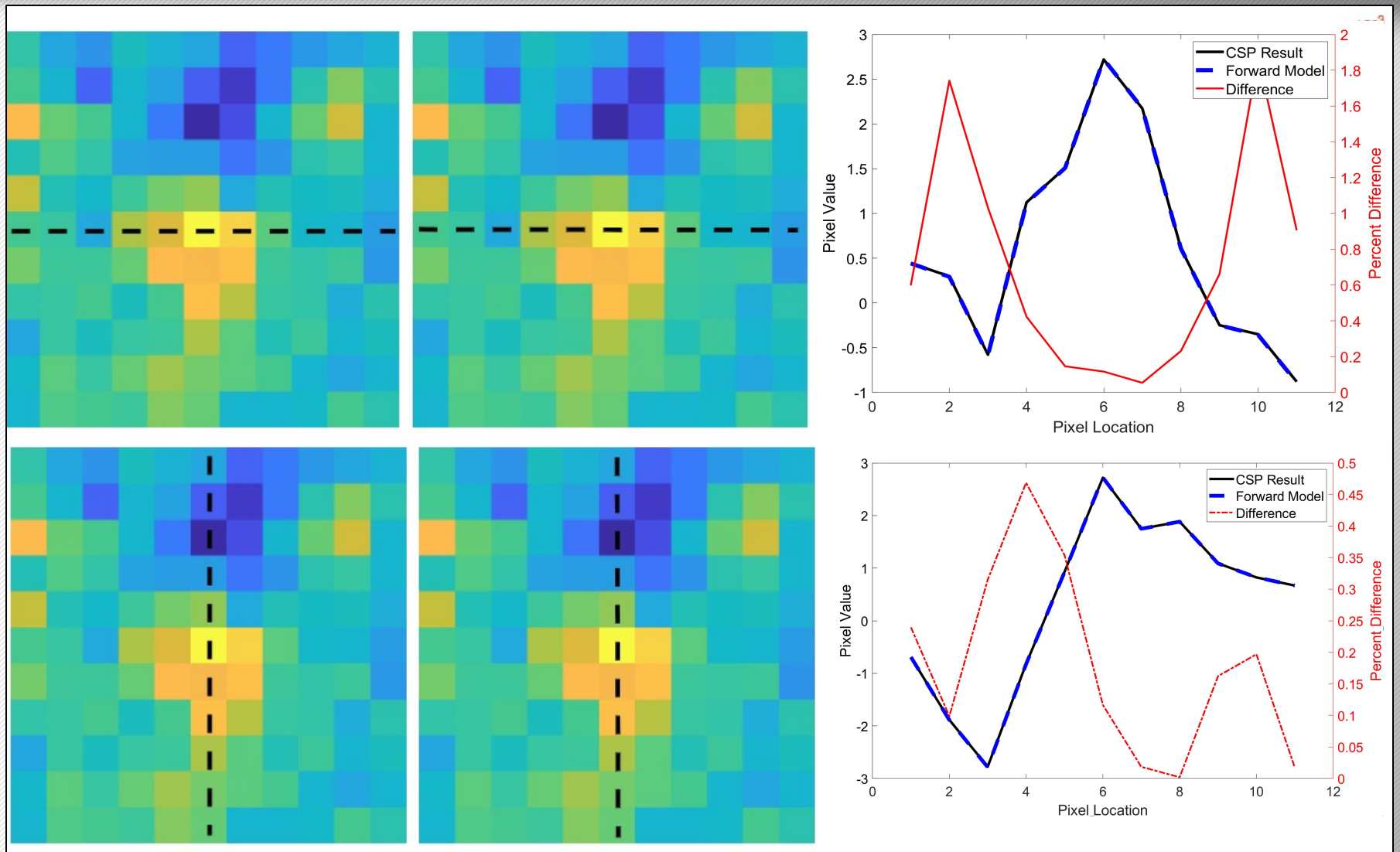
New Strategy – Forward Model, Matched Filter

We want:

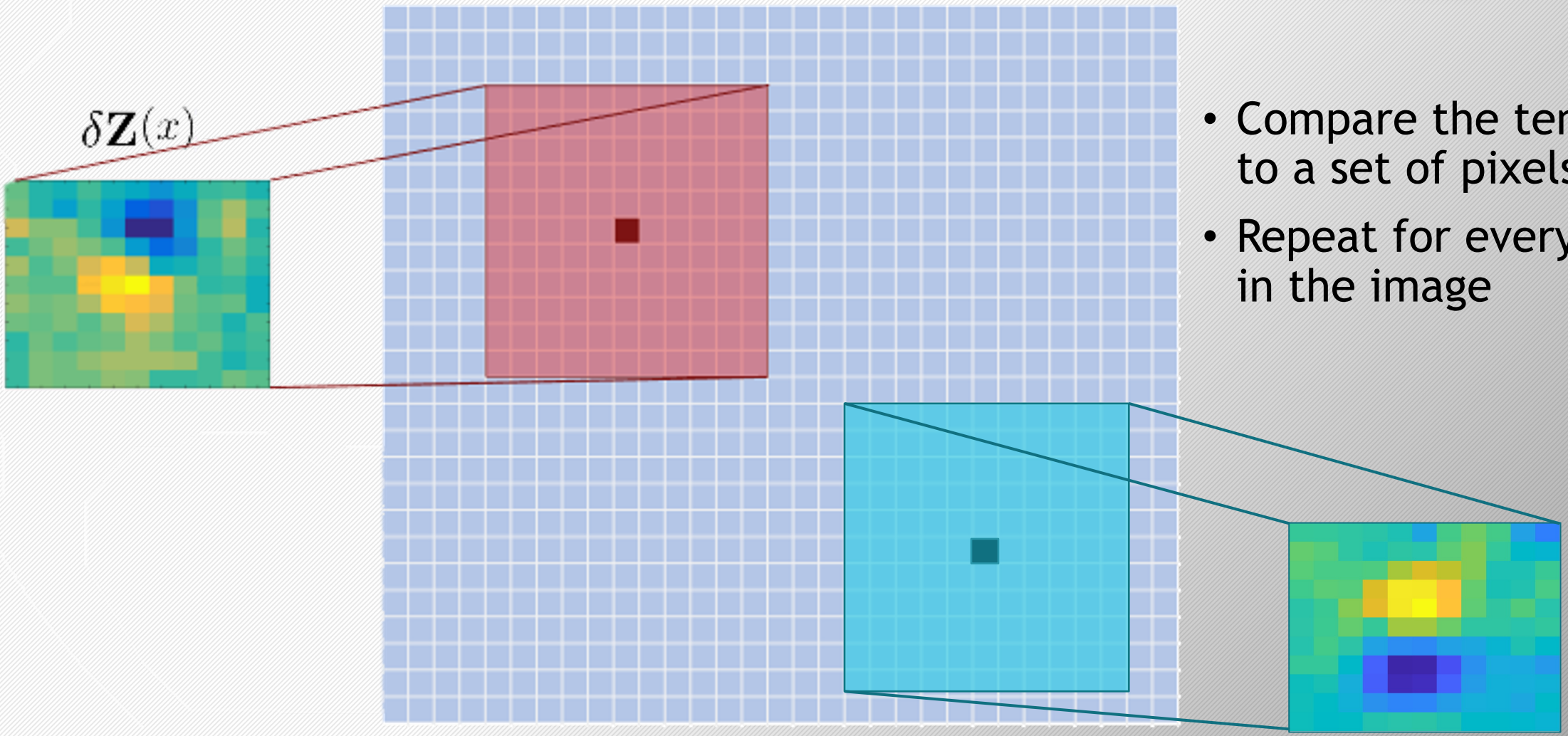
- Increase signal to noise ratio
- Remove false positives
- Model only the effects of the planet



Forward Model Accuracy

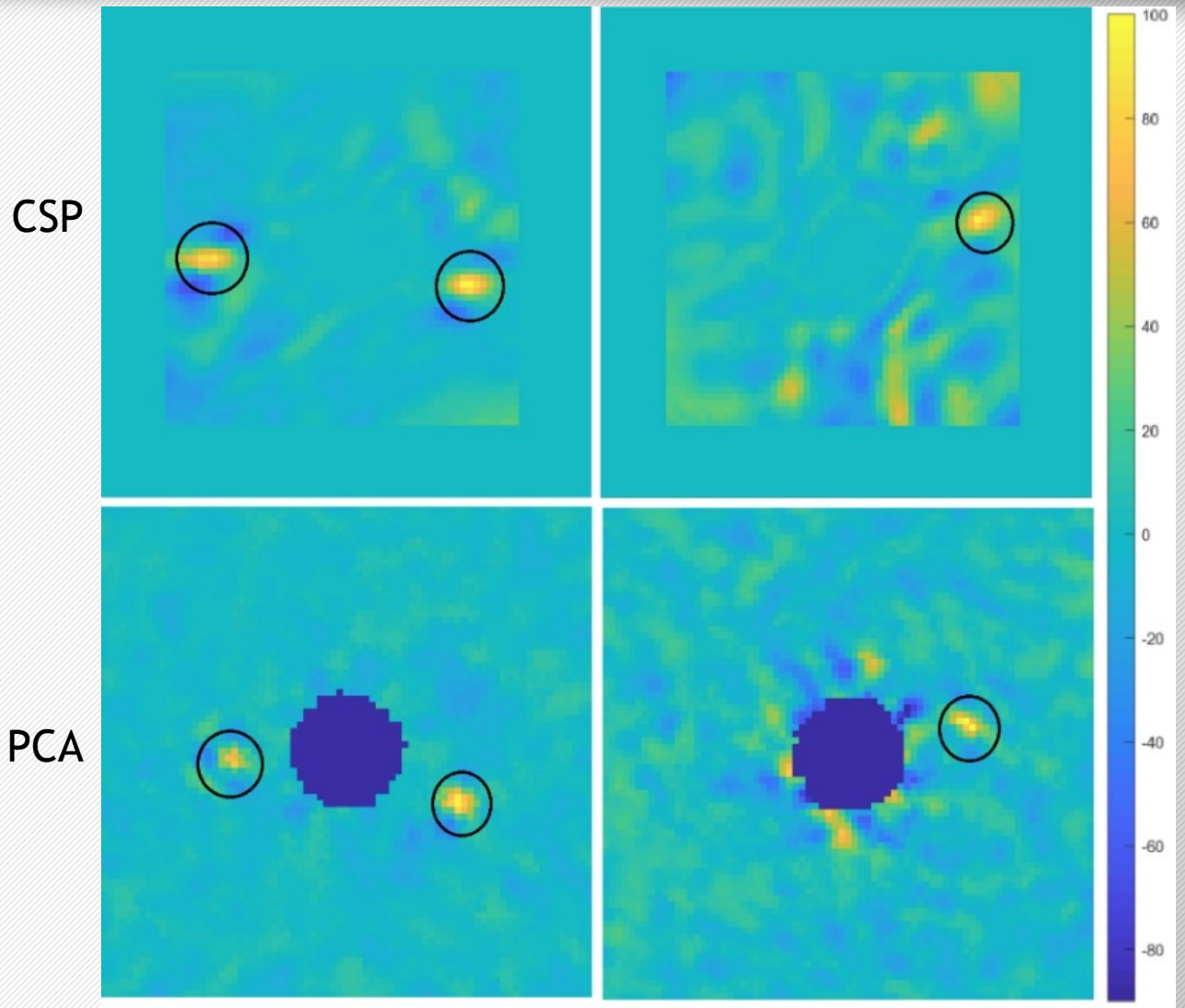


Matched Filter



- Compare the template to a set of pixels
- Repeat for every pixel in the image

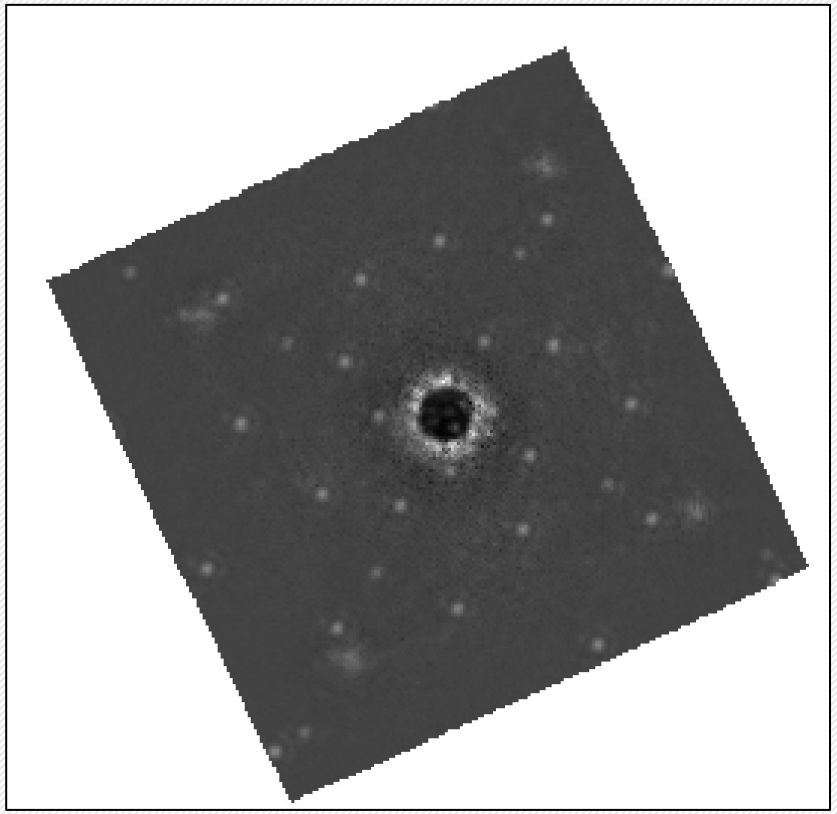
Results

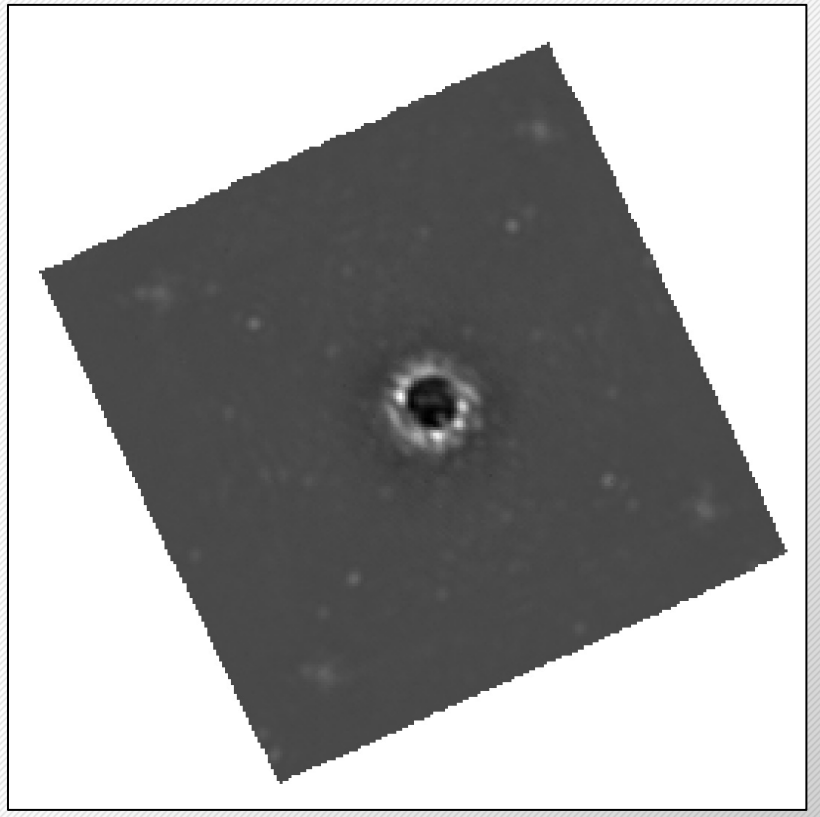


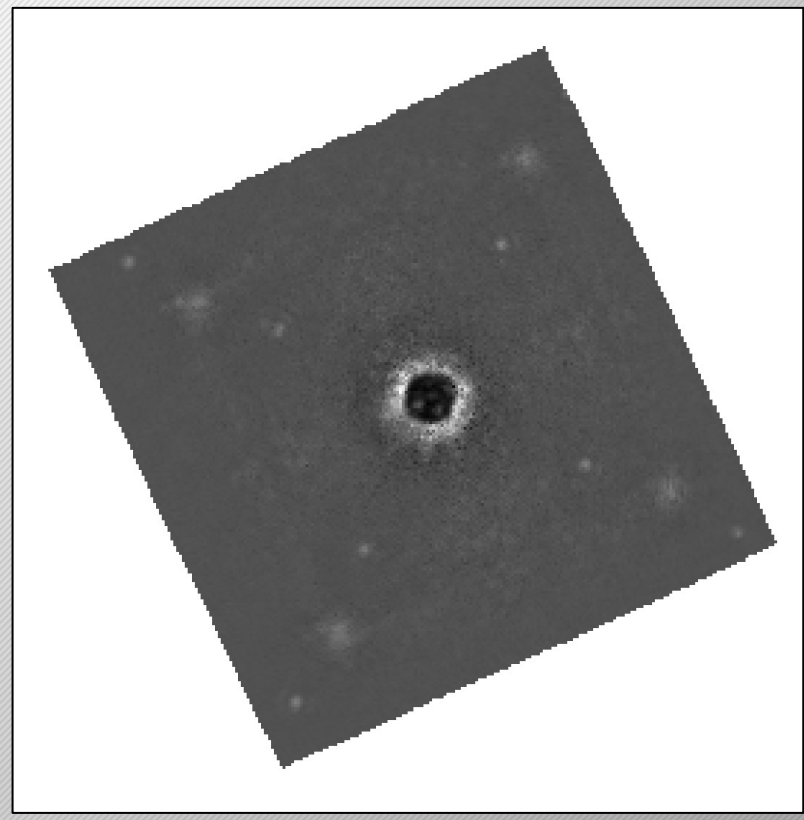
Signal to Noise Ratios

	CSP	PCA
B Pic 1	14.47	13.05
B Pic 2	11.79	9.97
HD 14706	6.90	10.65

Many Planets, Locations, and Datasets

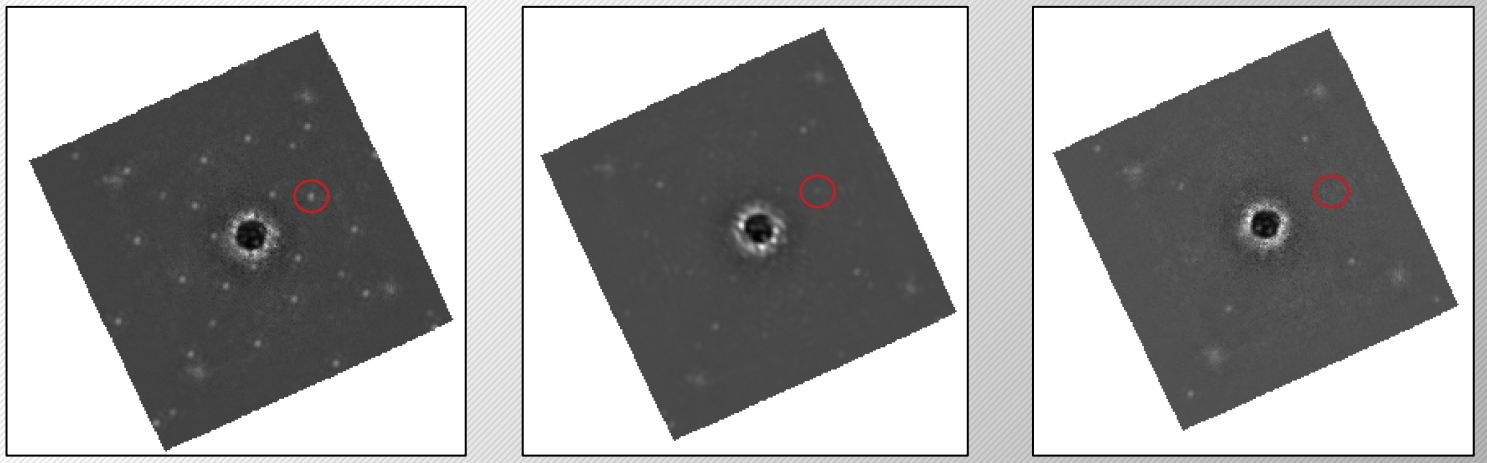






Determining Metrics

- Use 3 Contrast levels:
  - 10^{-5} – Above 5 SNR
  - 10^{-6}
  - 10^{-8} – Below 5 SNR
- For given injection, interpolate SNR



- Build contrast map:
  - Separation vs. contrast
  - SNR contours
- Build ROC curve to measure false-positive rate

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