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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

Detecting Exoplanet Atmospheres Through Spectroscopic Pixel-Level Decorrelation (sPLD)

Kevin Ortiz Ceballos & Néstor Espinoza

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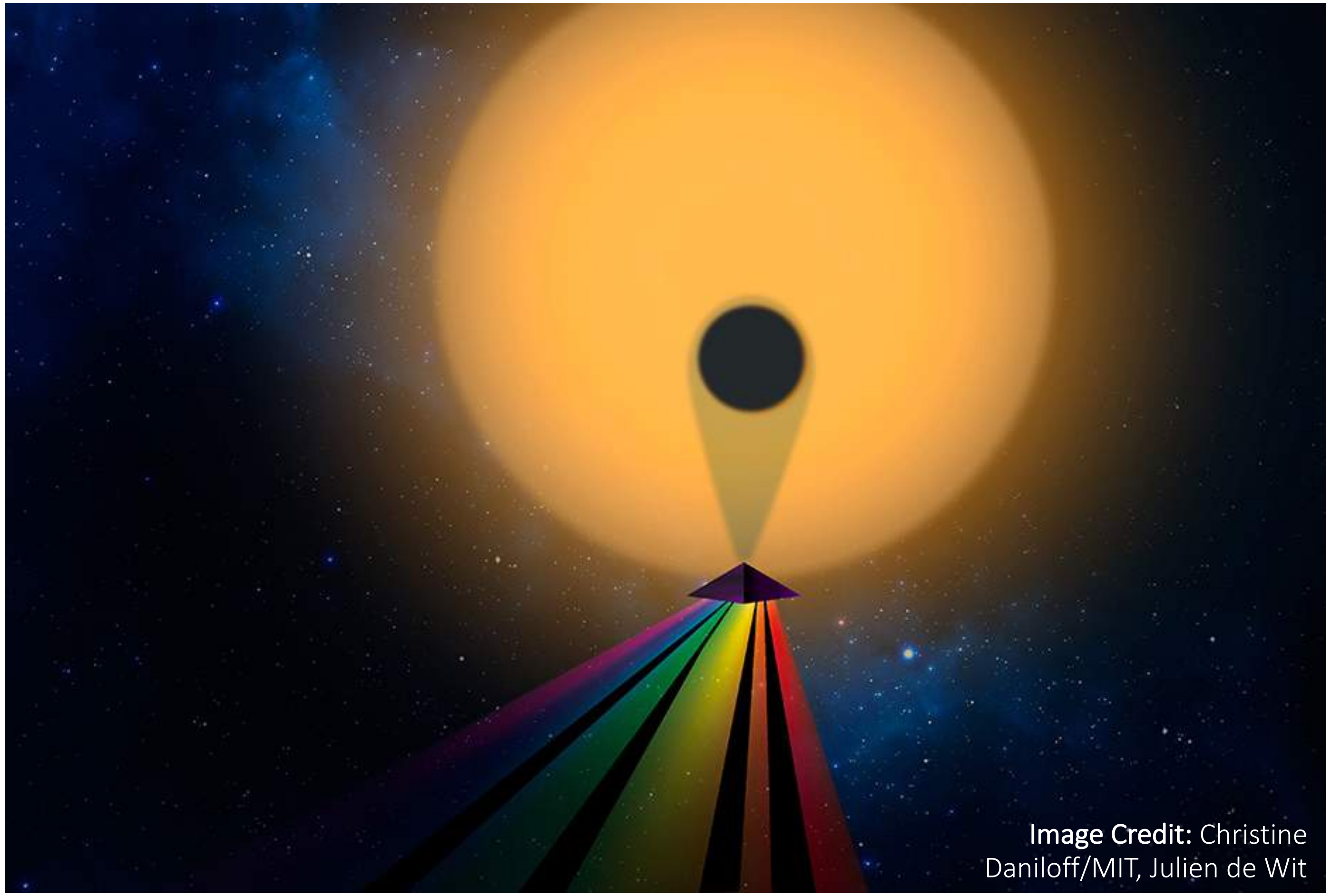
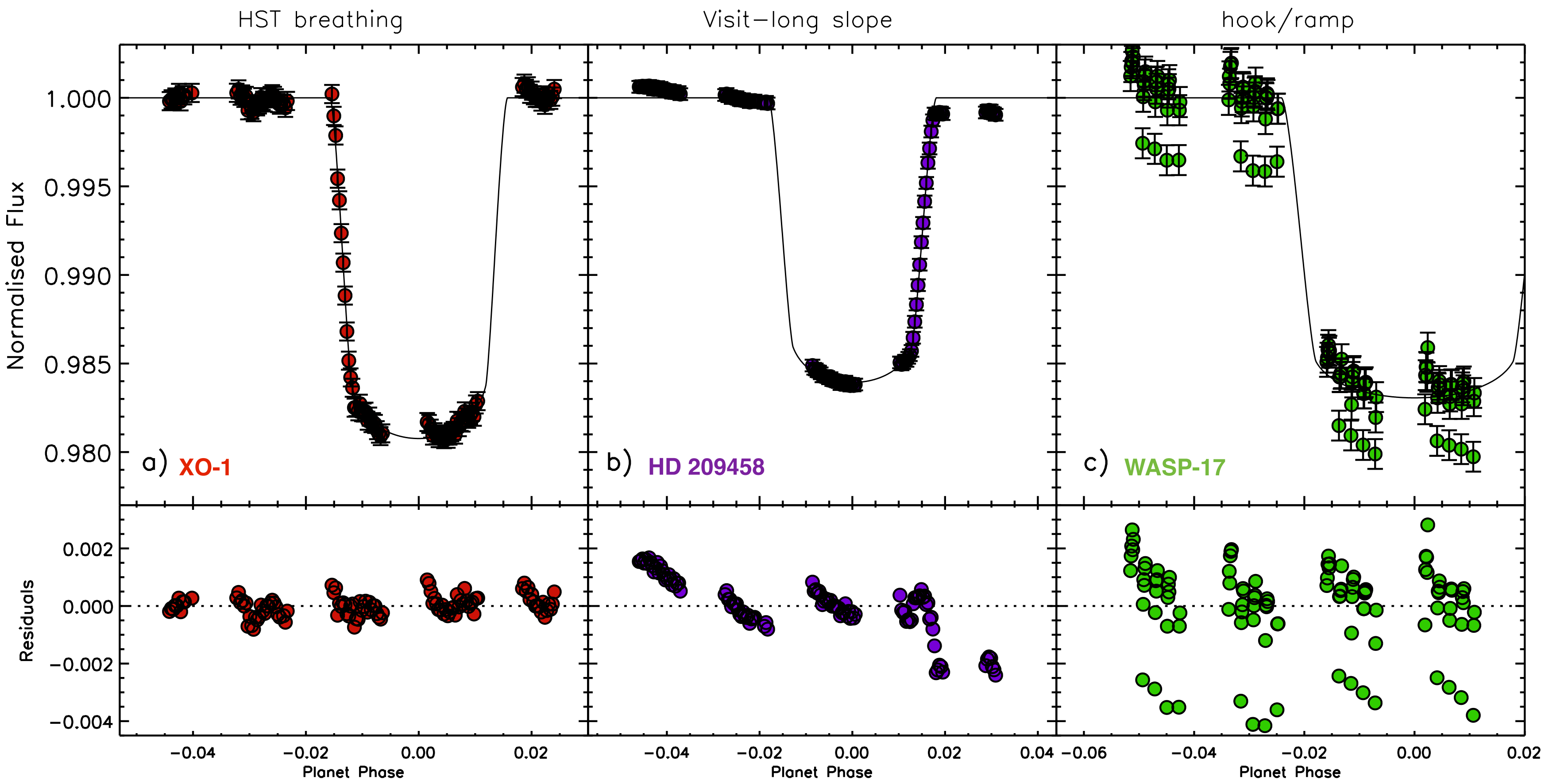
Introduction: Exoplanet Observations and PLD



- Transmission spectroscopy lets us detect the various elements that make up exoplanet atmospheres by measuring photometry at several wavelengths.

One problem: Systematics!



- An example of what HST systematics can look like (Wakeford et al., 2016).

Figure Credit: Wakeford et al., 2016

One possible solution: Pixel-Level Decorrelation

Pixel-Level Decorrelation (PLD) uses pixels themselves to correct systematics (Deming et al., 2015).

$$\Delta S^t = a + \sum_{i=1}^{N} c_i \hat{P}_i^t$$

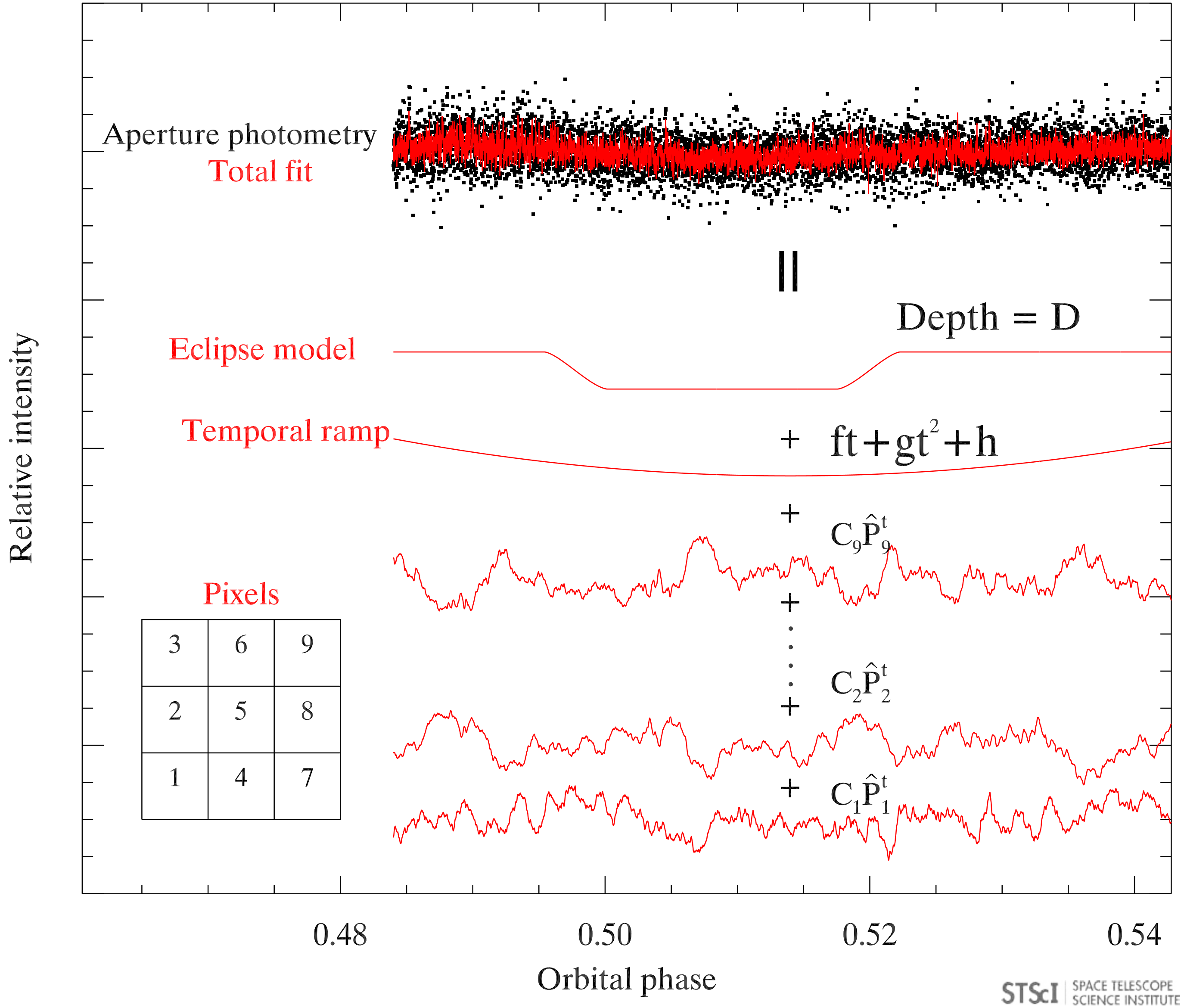
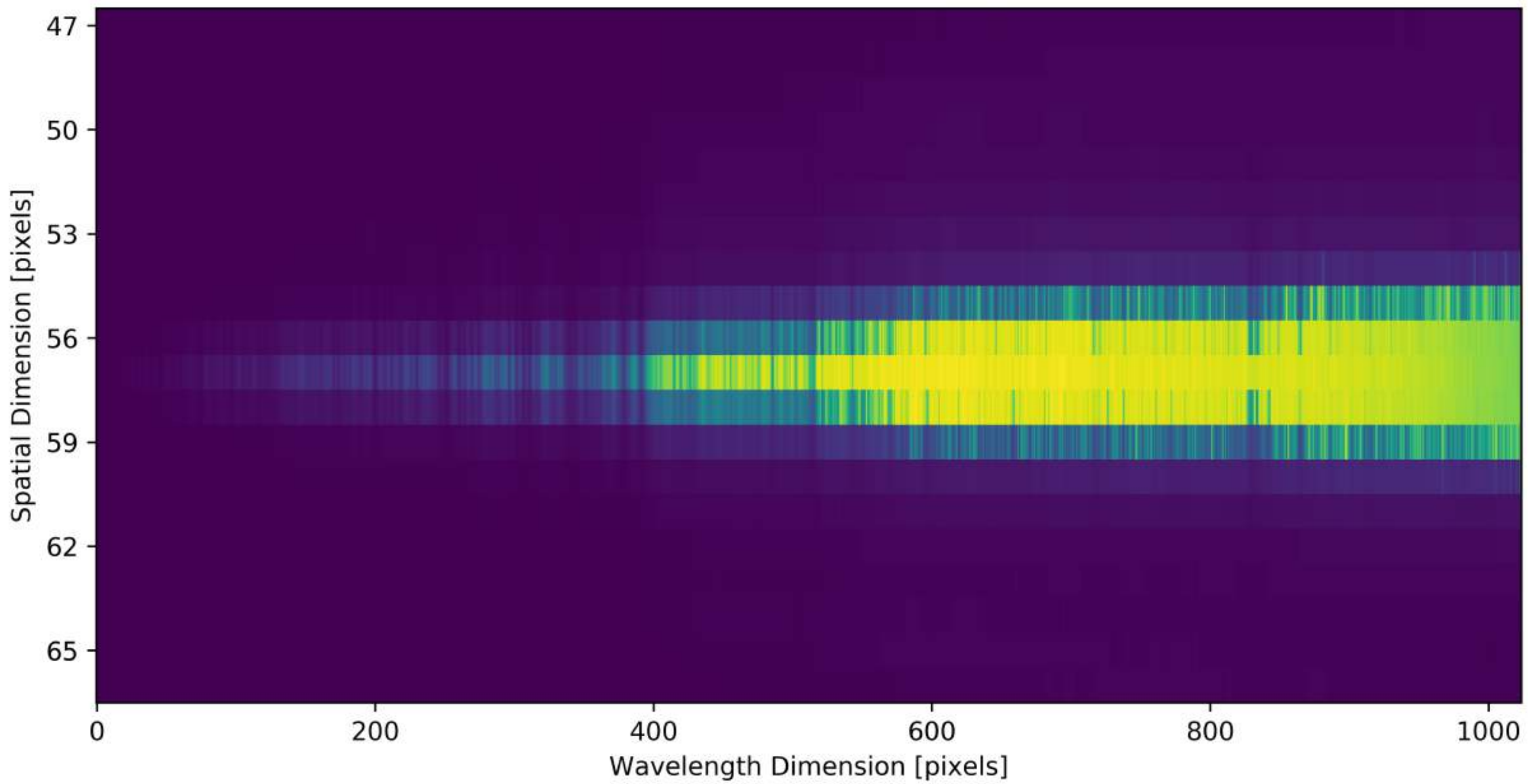


Figure Credit: Deming et al., 2015

Applying Spectroscopic PLD (sPLD) to Exoplanet Spectrophotometry with HST

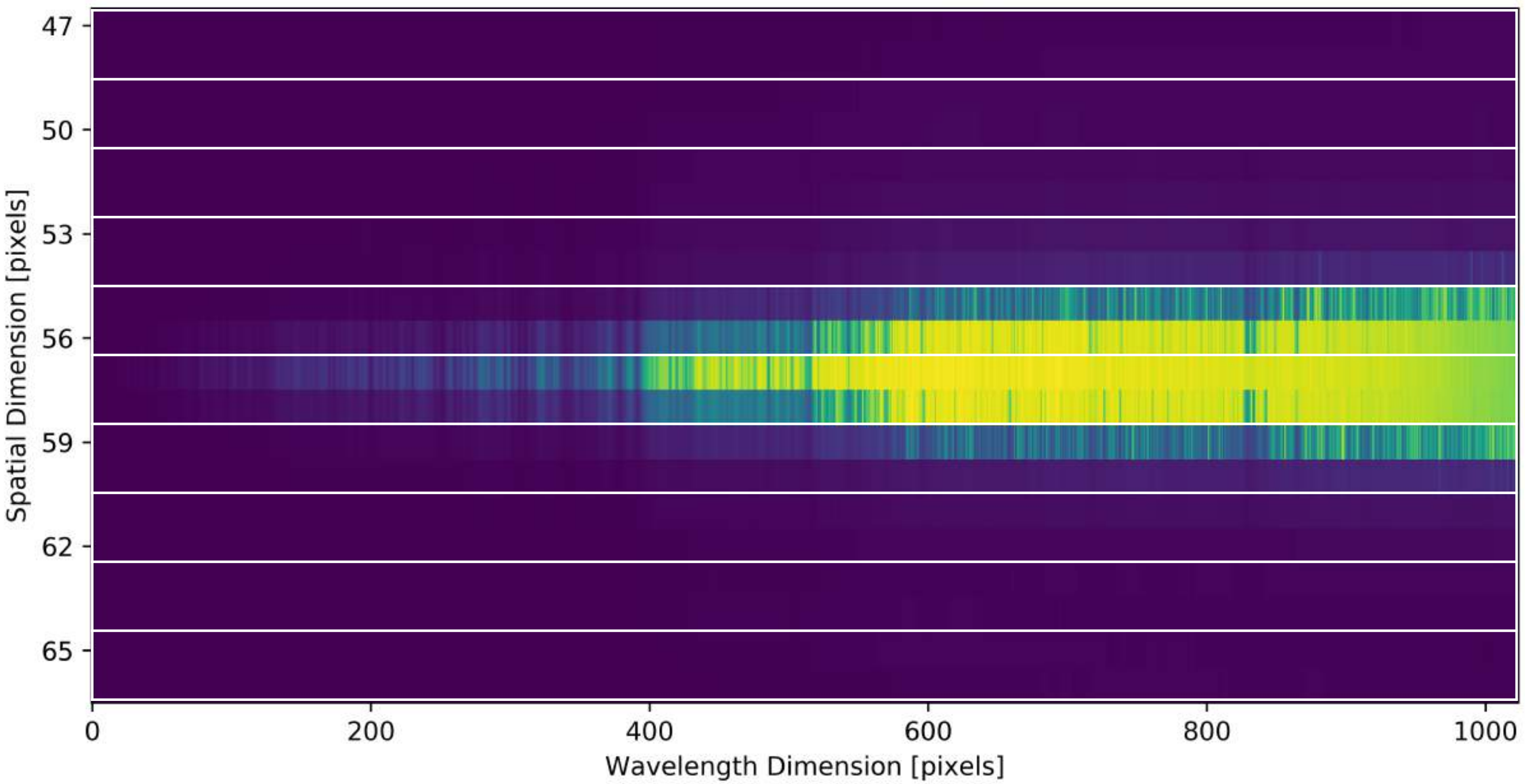
Getting to work: Looking at STIS data for HD 189733 b



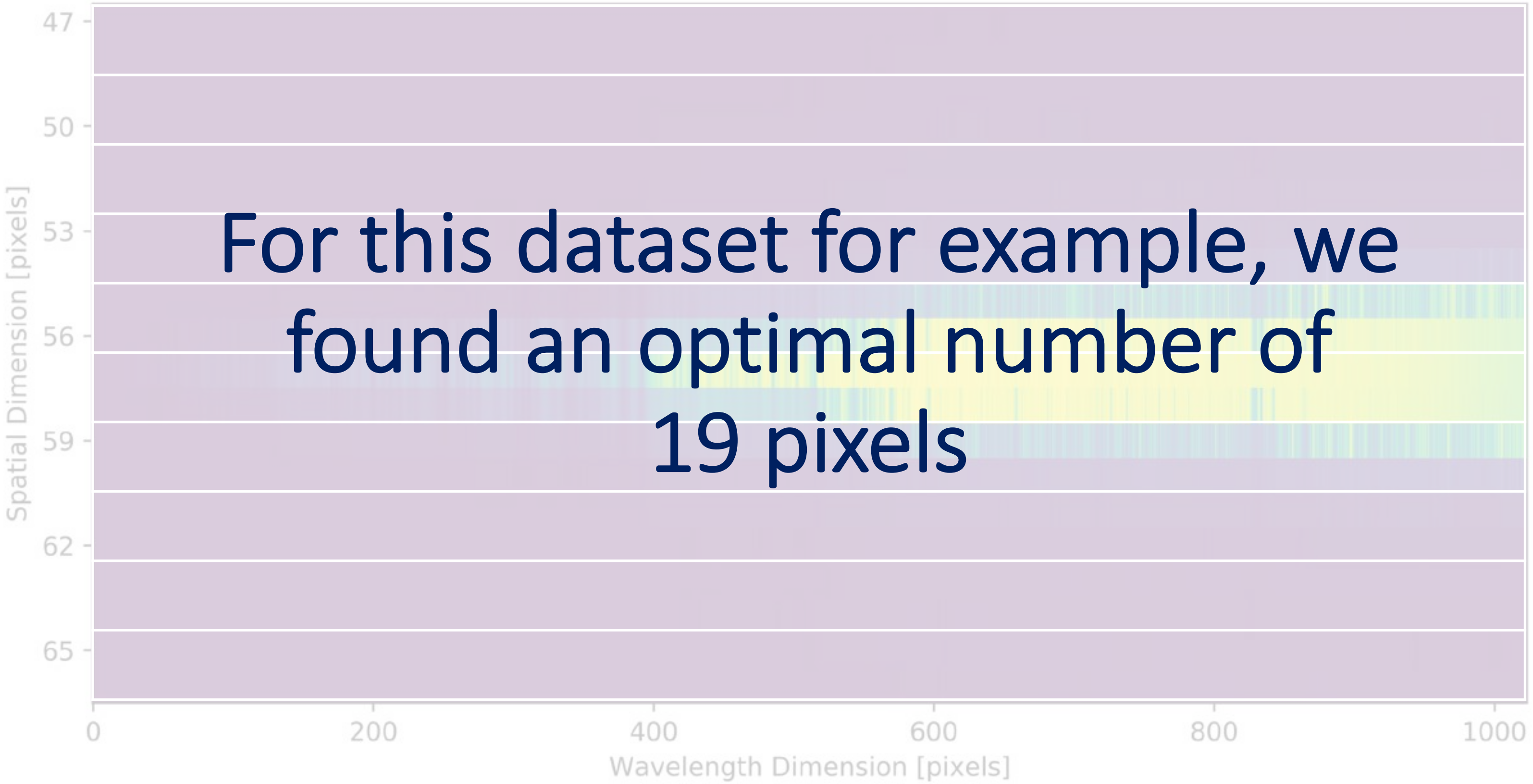
Getting to work: Looking at STIS data for HD 189733 b

To perform Pixel-Level Decorrelation, we split our STIS image into “pixel” components…

Getting to work: Looking at STIS data for HD 189733 b

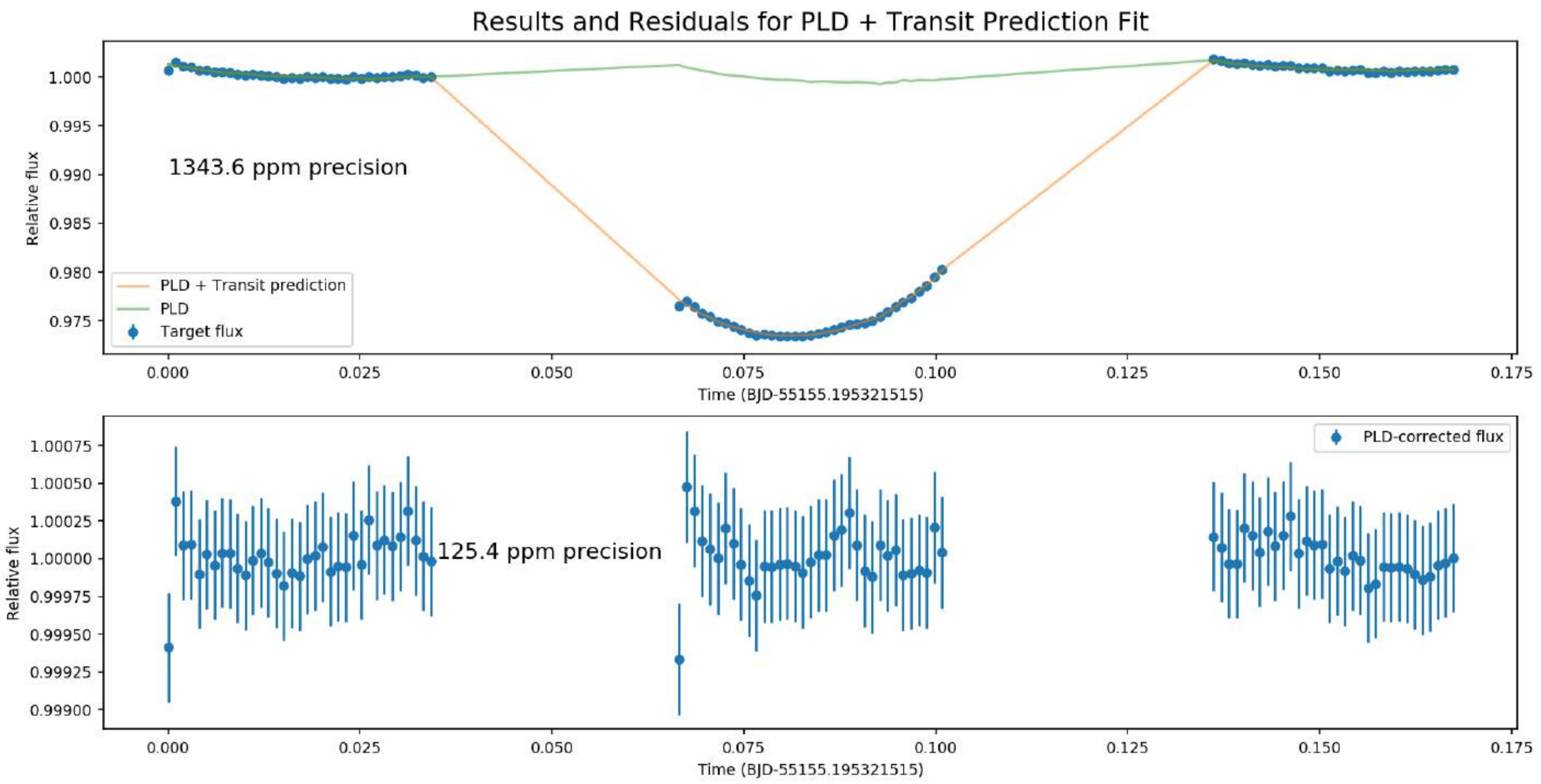


Getting to work: Looking at STIS data for HD 189733 b



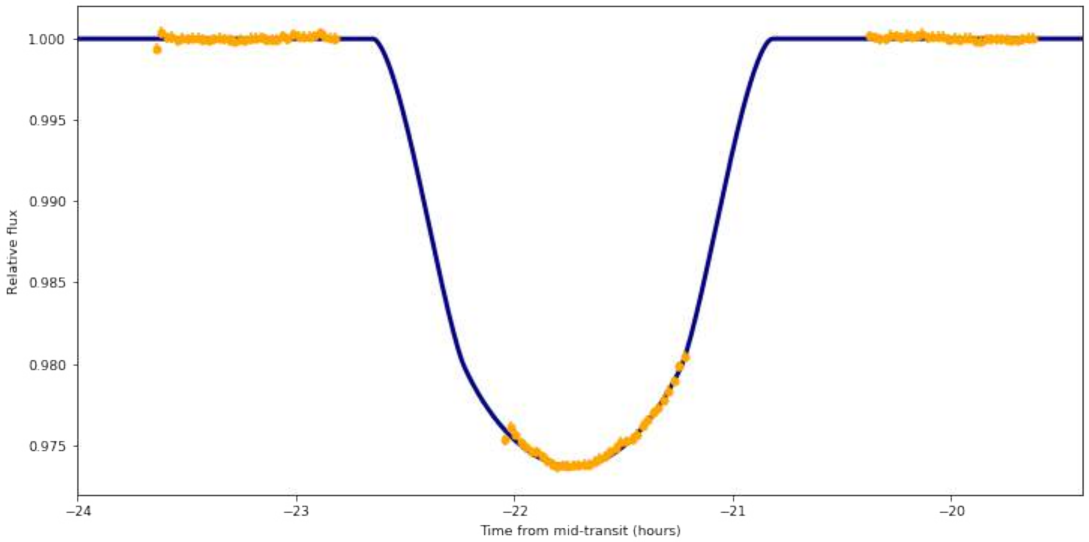
For this dataset for example, we found an optimal number of 19 pixels

Results for HD 189733b



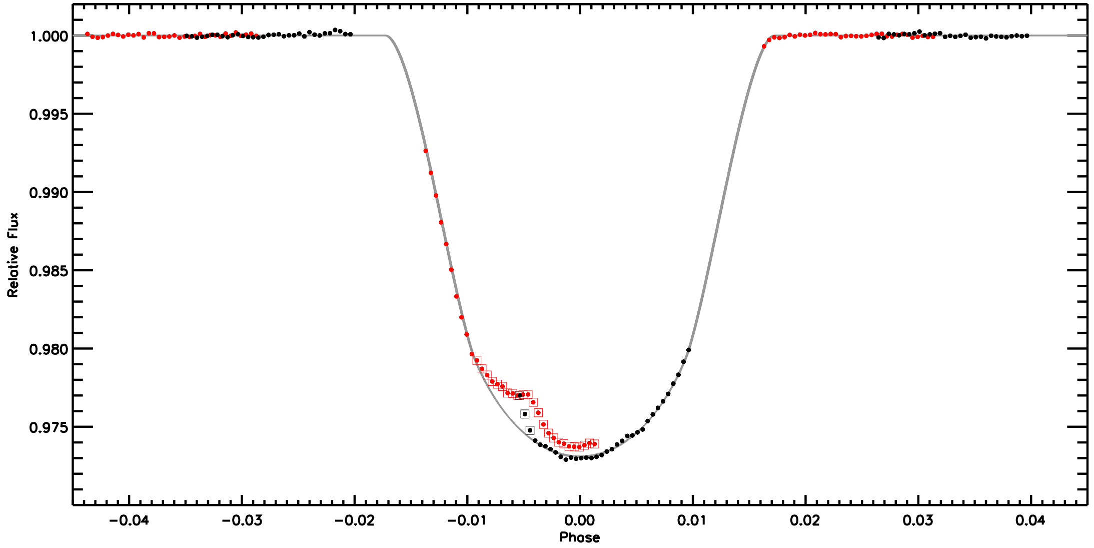
Results for HD 189733b

In the end, we find that our fit using PLD is consistent with the original published results from the 2011 observations (Sing et al., 2011).



Our result

4 regressors (3 PCA elements and 1 time slope)



Sing et al., 2011 (Visit in black)

6 regressors

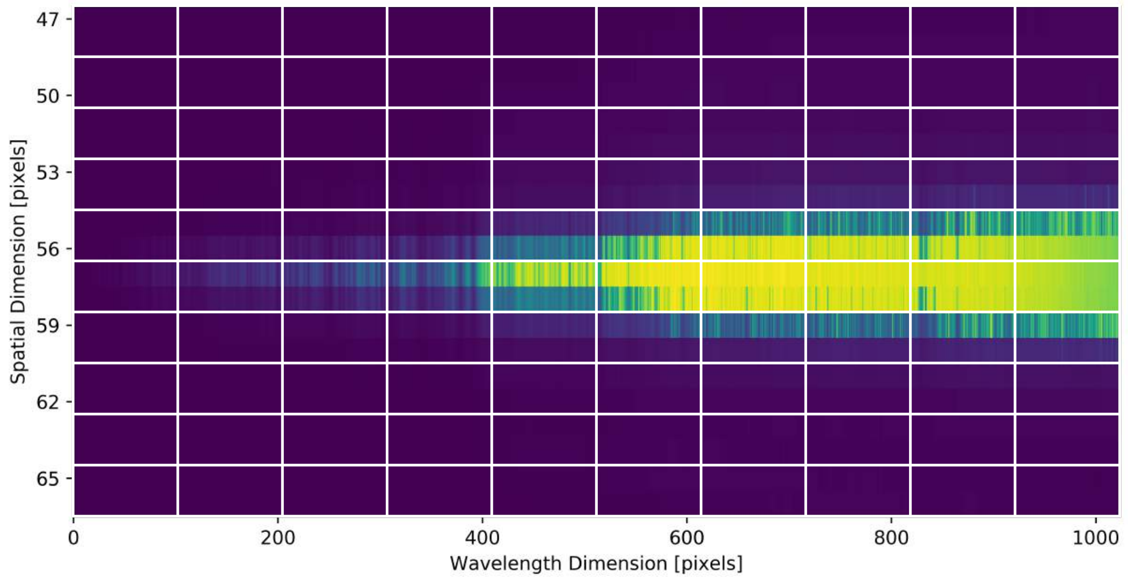
Conclusions

- PLD is a powerful technique to efficiently model systematic trends in time-series observations.
- PLD works very well for HST/STIS* spectrophotometric data! White-light light curve fits using PLD give us comparable results to more complex modeling in the literature.
- Given JWST instruments like NIRCam, NIRSpec and MIRI have a very similar positioning of spectra in the detectors, this technique might be also applicable to them.

*We also tested PLD with HST/WFC3 but it did not work as well (not shown). Why? Ask us!

Next Steps

- Currently working on PLD with pixels also divided along the spectral dimension.
- We will also examine applications to JWST detections of exoplanet atmospheres.



References

1. Wakeford, H.R., Sing, D.K., Evans, T., Deming, D., Mandell, A. (2016) **Marginalizing Instrument Systematics in HST WFC3 Transit Light Curves.** *The Astrophysical Journal, 819*(1), 10.
2. Deming, D., Knutson, H., Kammer, J., Fulton, B. J., Ingalls, J., Carey, S., ... & Cowan, N. (2015). **Spitzer secondary eclipses of the dense, modestly-irradiated, giant exoplanet HAT-P-20b using pixel-level decorrelation.** *The Astrophysical Journal*, *805*(2), 132.
3. Sing, D. K., Pont, F., Aigrain, S., Charbonneau, D., Désert, J. M., Gibson, N., ... & Des Etangs, A. L. (2011). **Hubble Space Telescope transmission spectroscopy of the exoplanet HD 189733b: high-altitude atmospheric haze in the optical and near-ultraviolet with STIS**. *Monthly Notices of the Royal Astronomical Society*, *416*(2), 1443-1455.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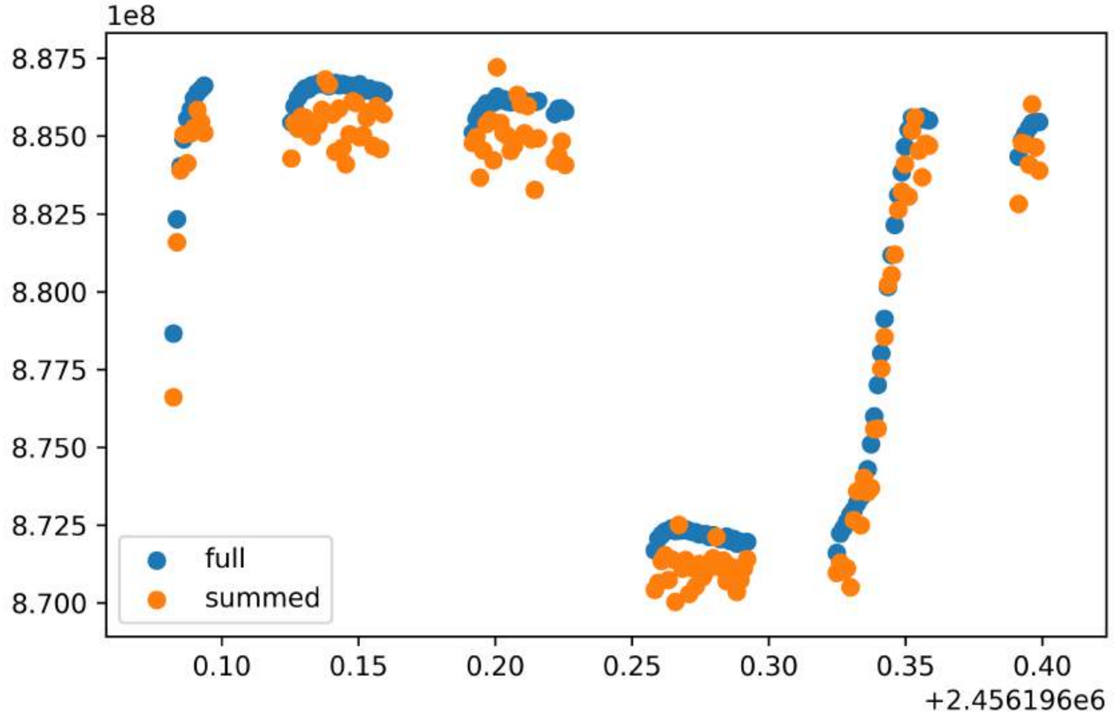
Backup Slides

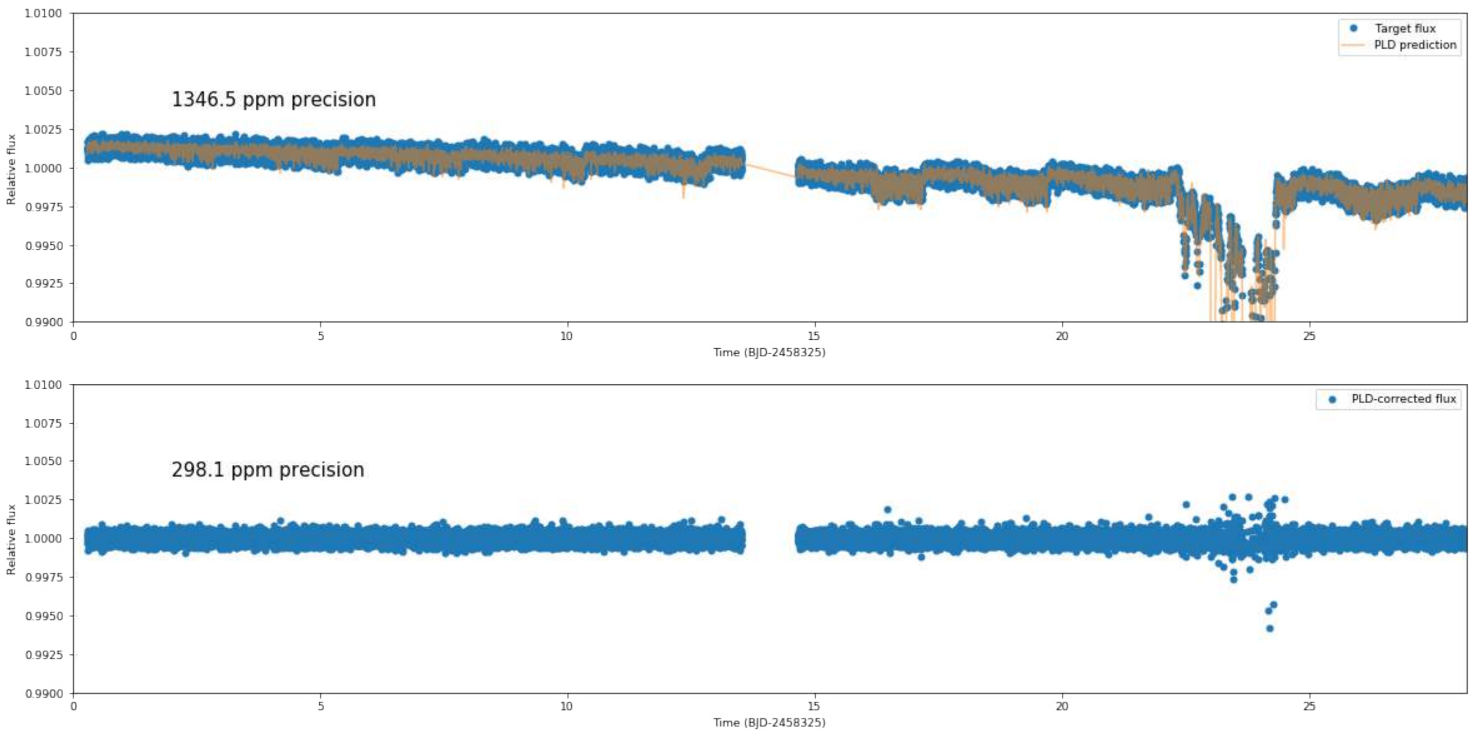
WFC3 Test with PLD

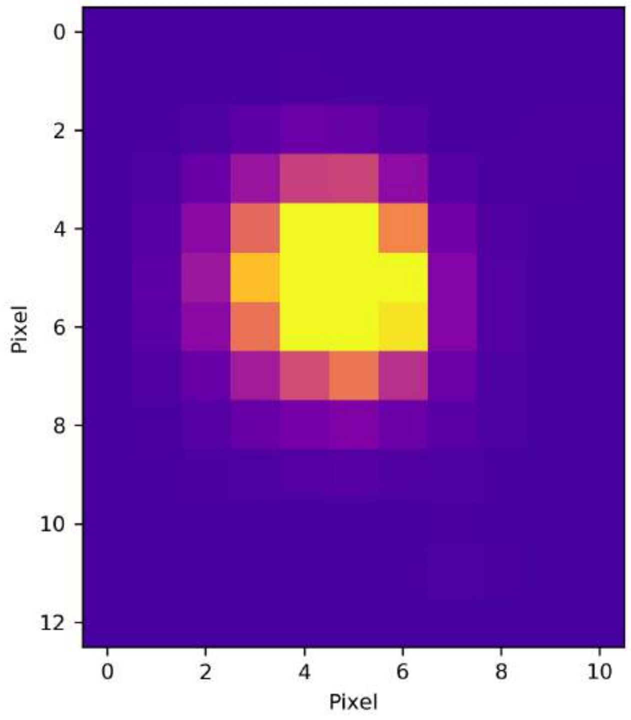
- Our hypothesis is that PLD acts as an excellent decorrelator as long as the signals introducing the systematics are not at the detector level.
- Because the ‘hook’ seen in HST/WFC3 is a detector-level systematic (due to charge trapping), PLD is unable to efficiently correct for it.



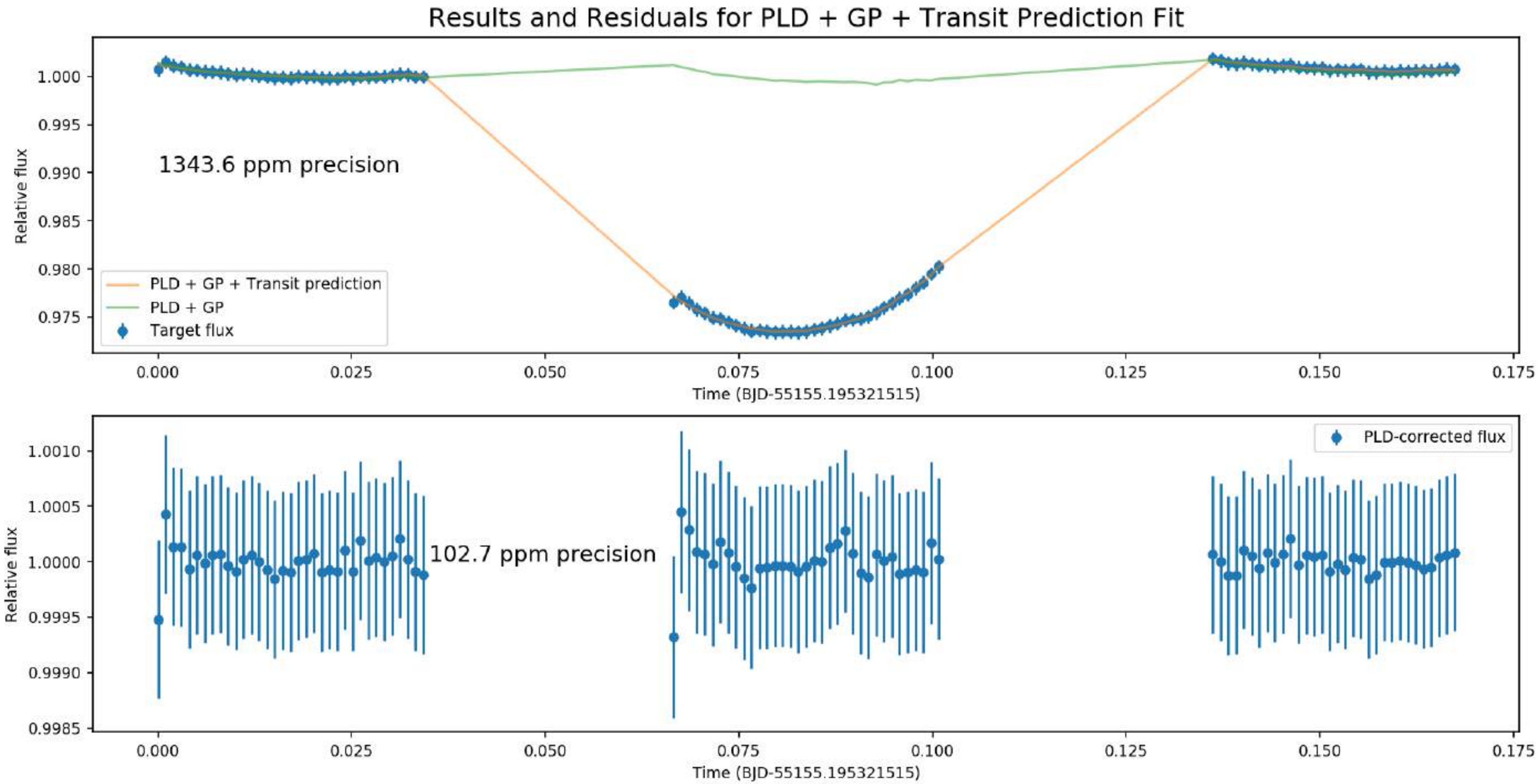
Testing out PLD with Exoplanet Photometry

- We first tested out PLD using the TESS photometry data for exoplanet candidate TOI-141 b, using the Juliet software package to perform the fits in Python.
- The result was a dramatic increase in precision for the light curve!





Results for HD 189733b: With GPs



The planet: HD 189733 b

- HD 189733 b is the closest transiting Hot Jupiter to our Solar System.
- We revisited the data from Sing et al. (2011) to test PLD on these spectroscopic observations.

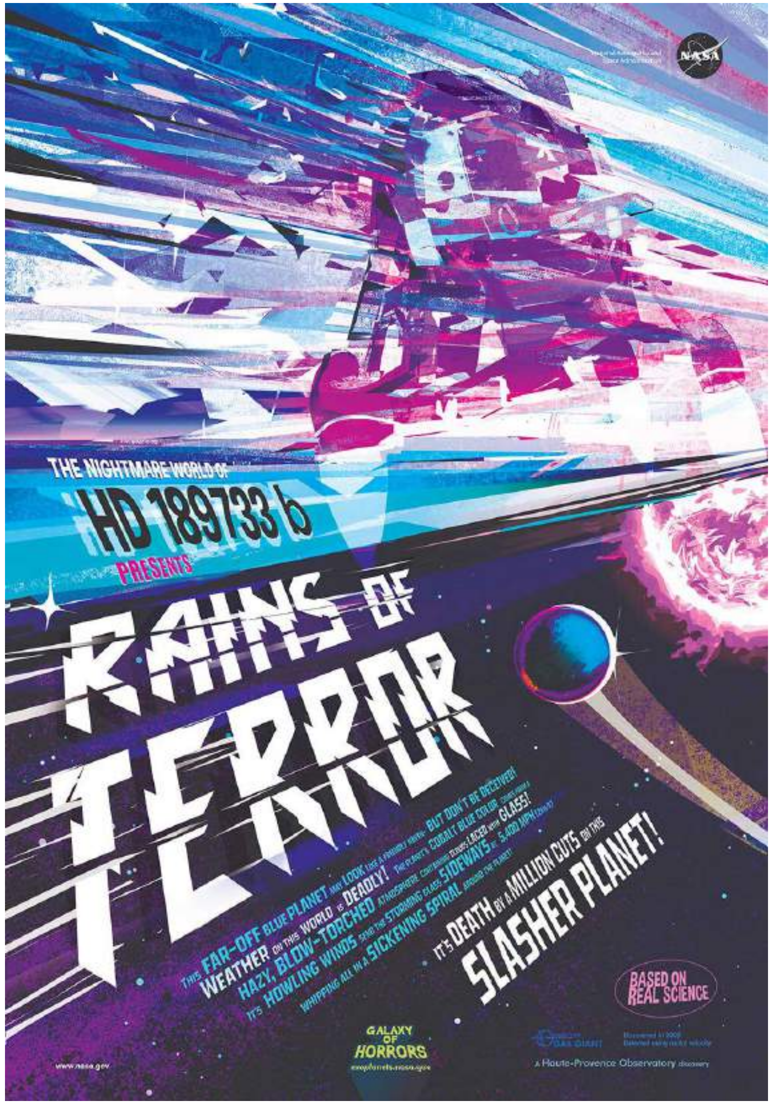
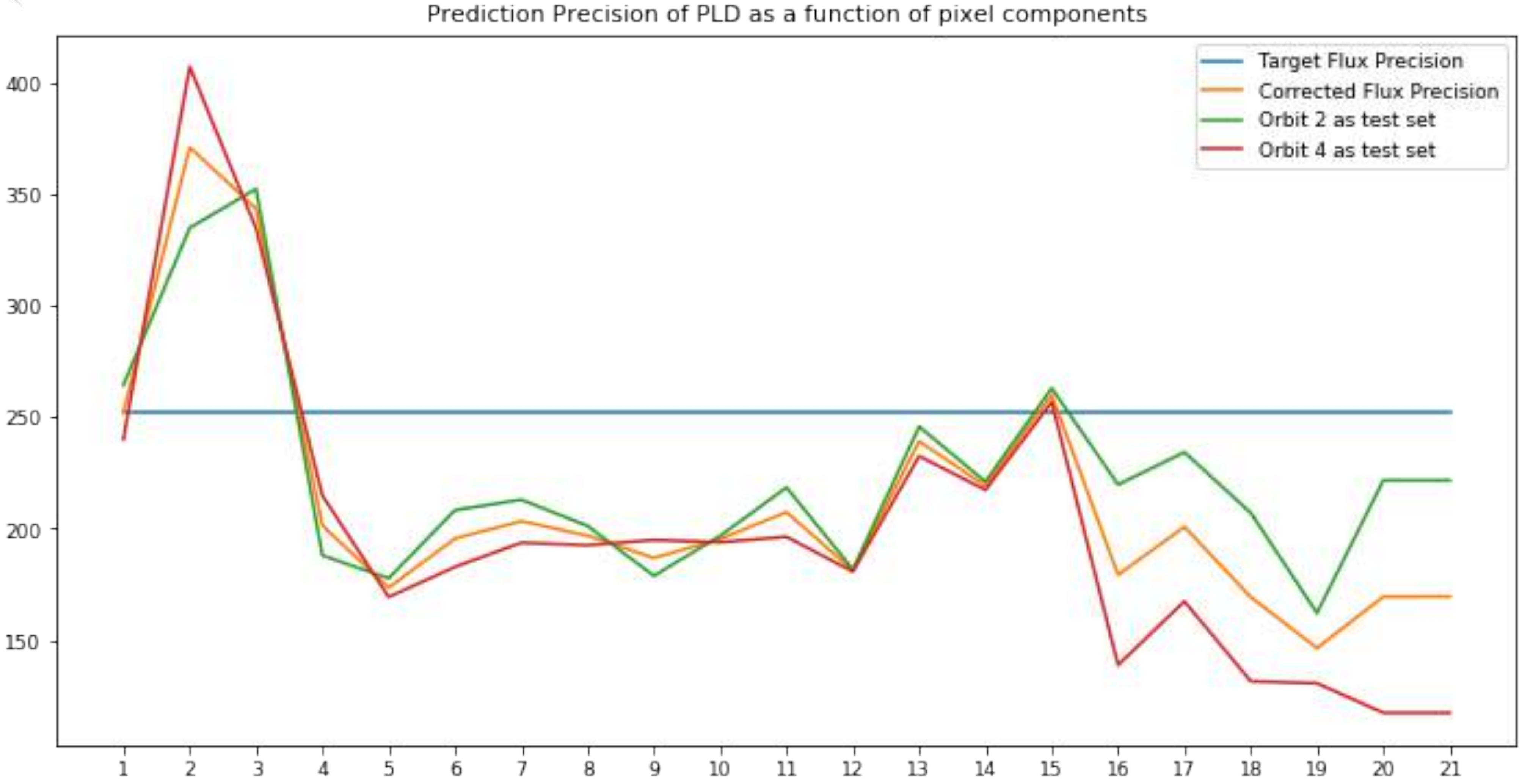
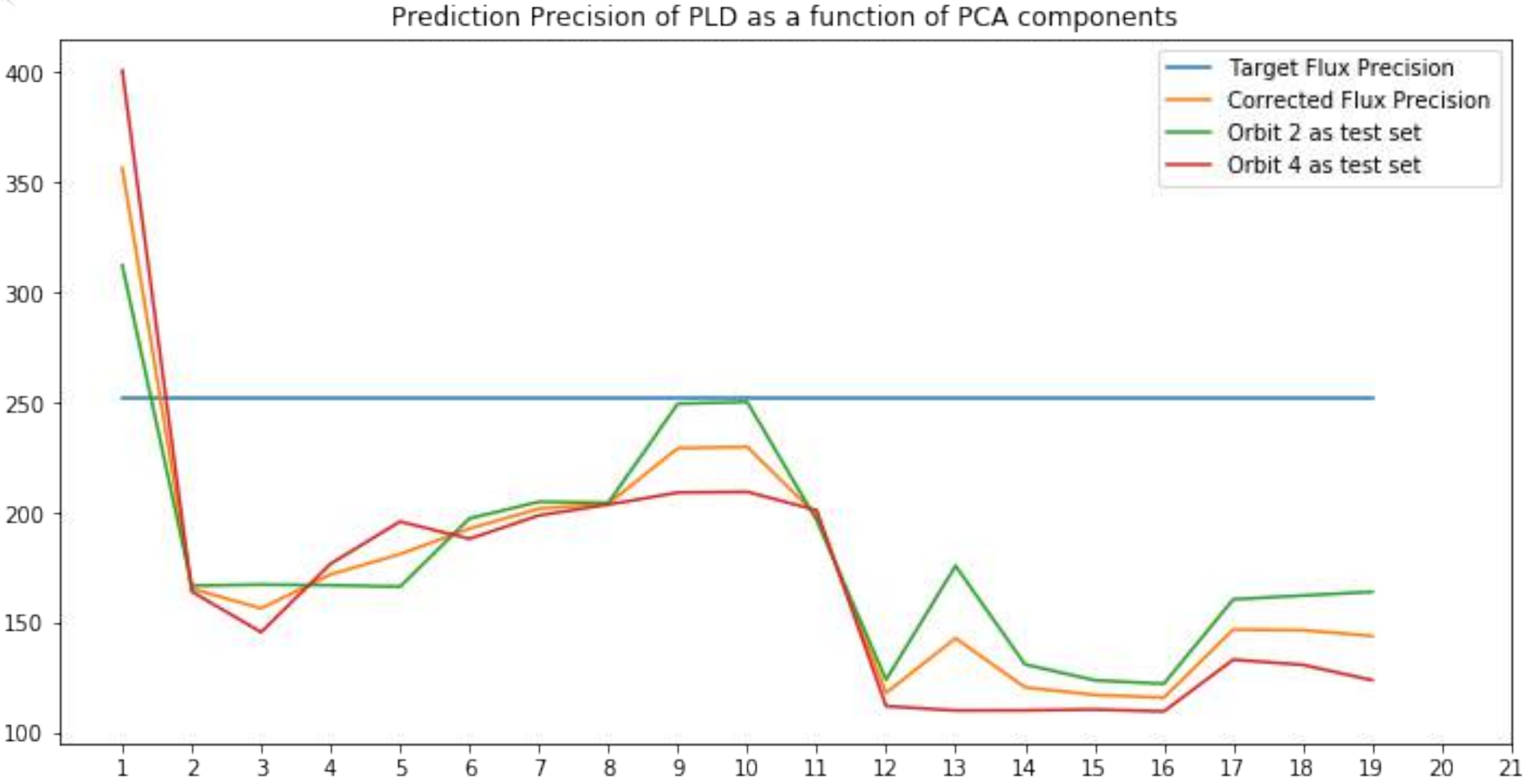


Image Credit: NASA-JPL/Caltech

Optimal Number of Pixels

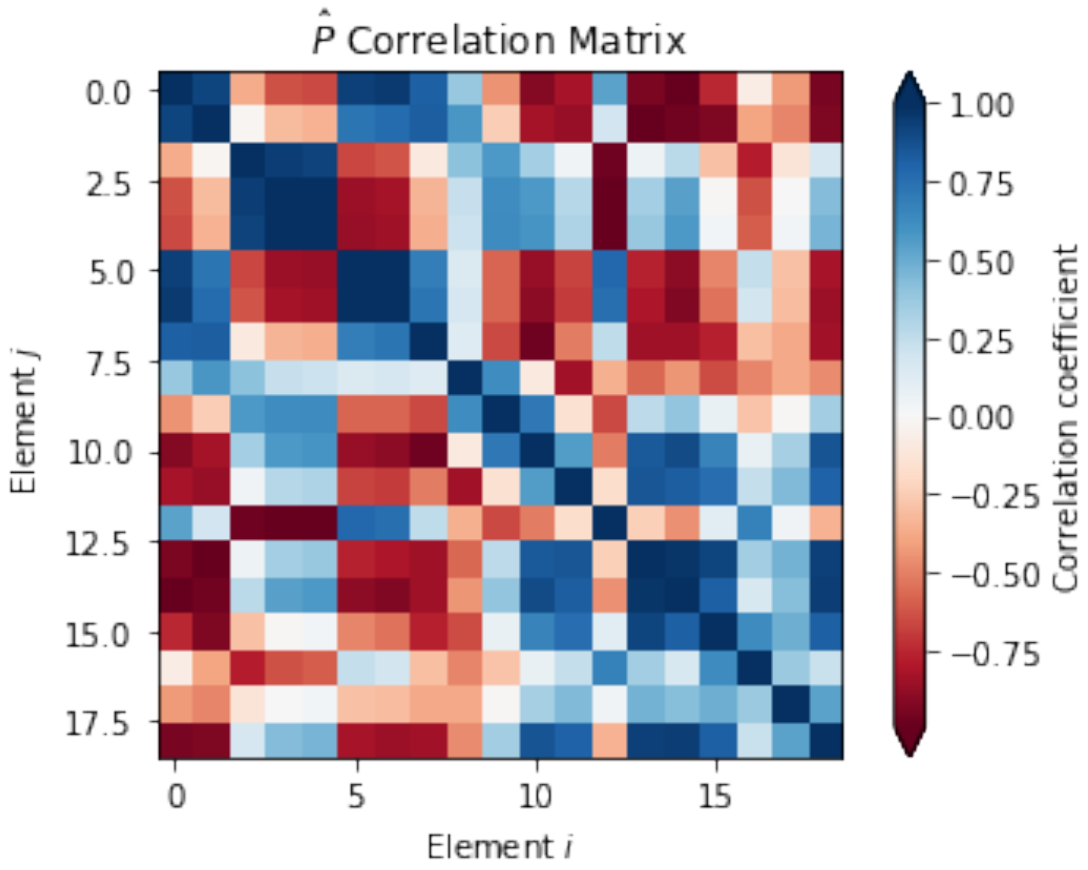


Optimal Number of PCA Components

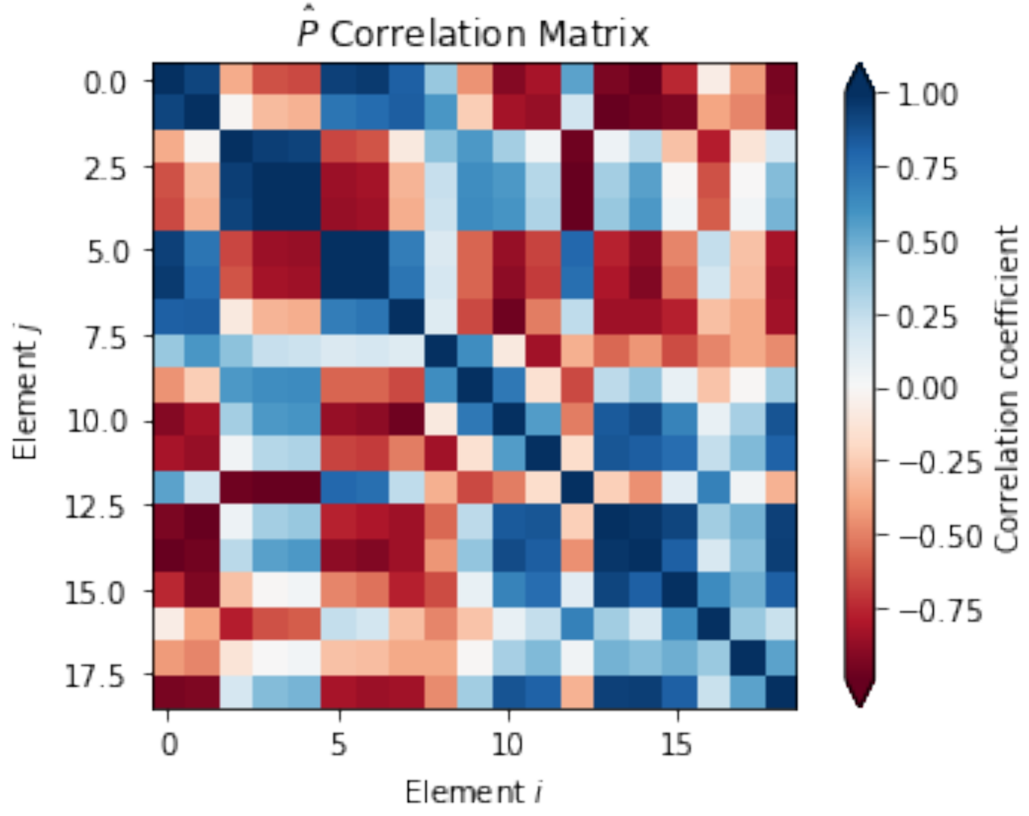


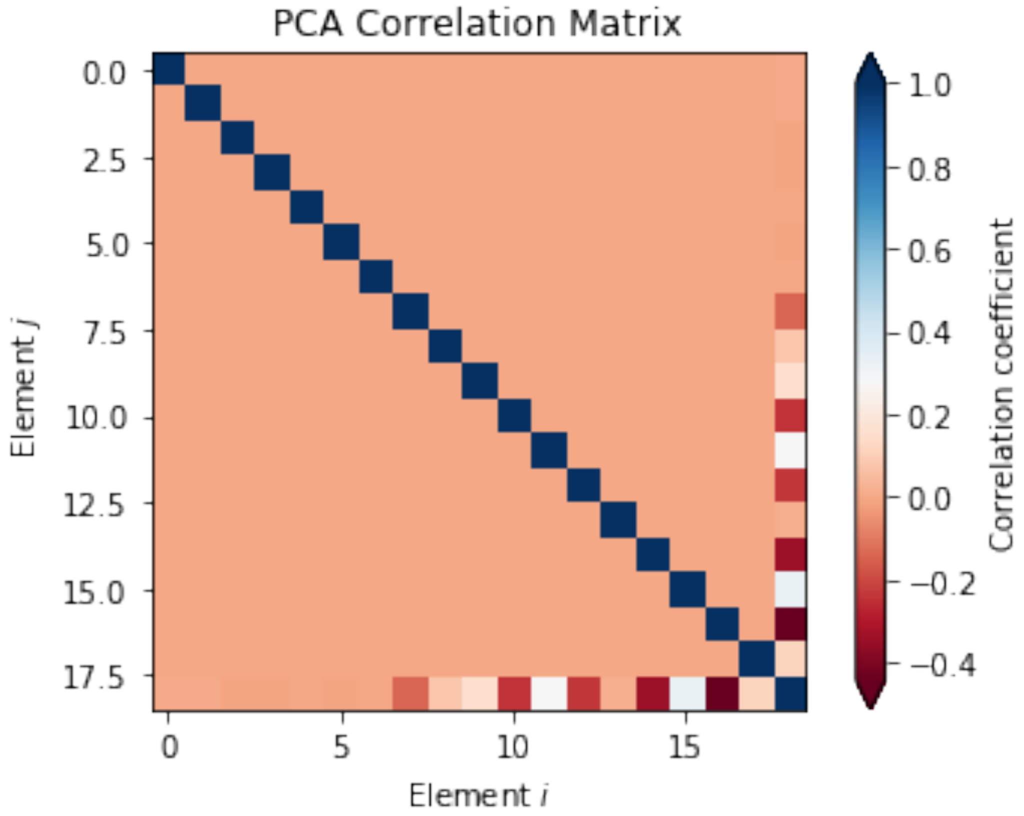
Adding Principal Component Analysis

- Another key method also implemented was Principal Component Analysis (PCA).
- PCA reduces noise from correlated pixels, and reduces the regressors from 19 to 3.

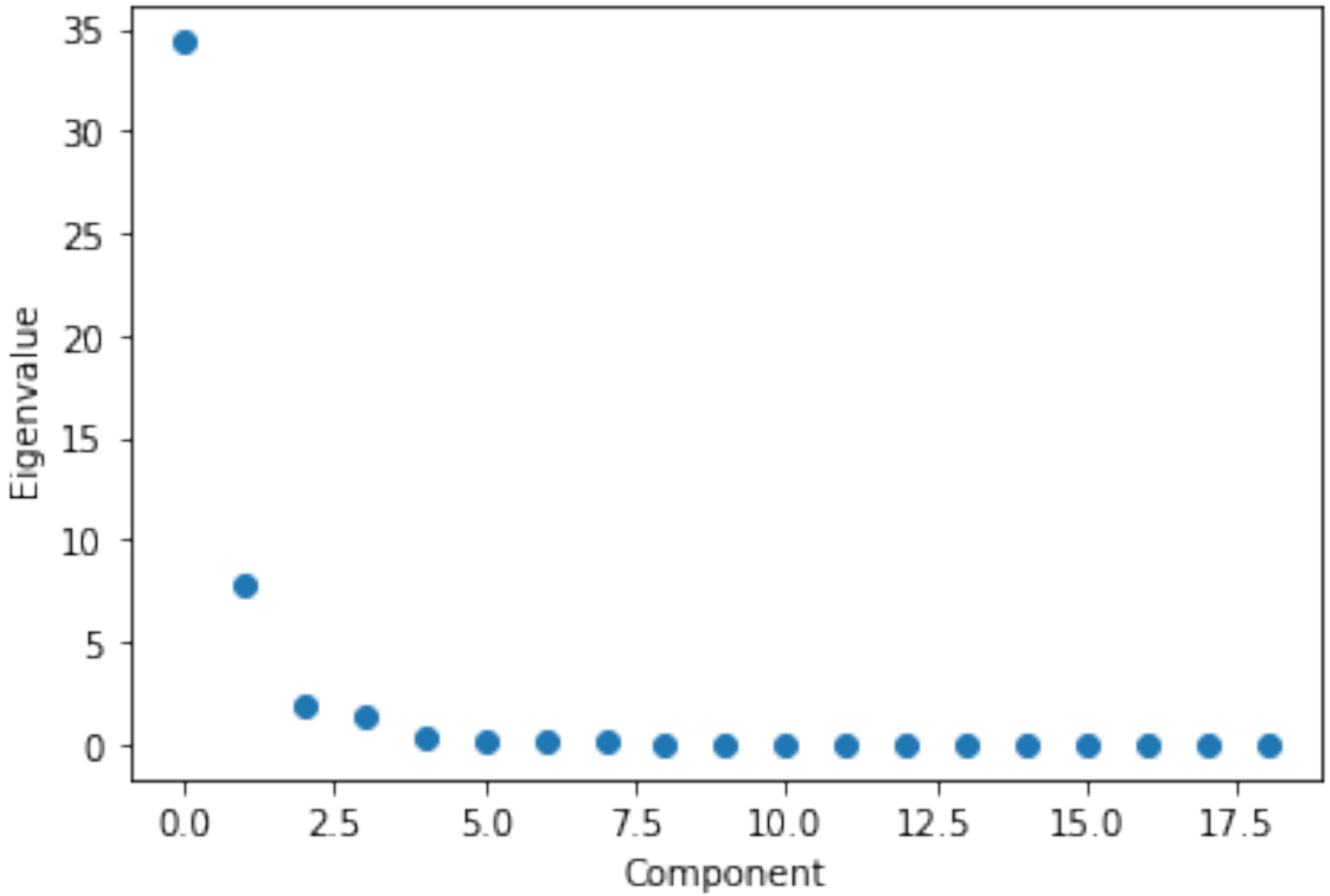


Pre- and Post-PCA Correlation Matrices





PCA Eigenvalues



The telescope: Hubble Space Telescope!

Introduction: Space Telescopes, Exoplanet Observations, and PLD

- Space telescopes are able to observe the various elements that make up exoplanet atmospheres, but can be plagued with all sorts of systematic errors.
- We propose to use the technique of Pixel-Level Decorrelation (PLD) to increase the precision of these observations.

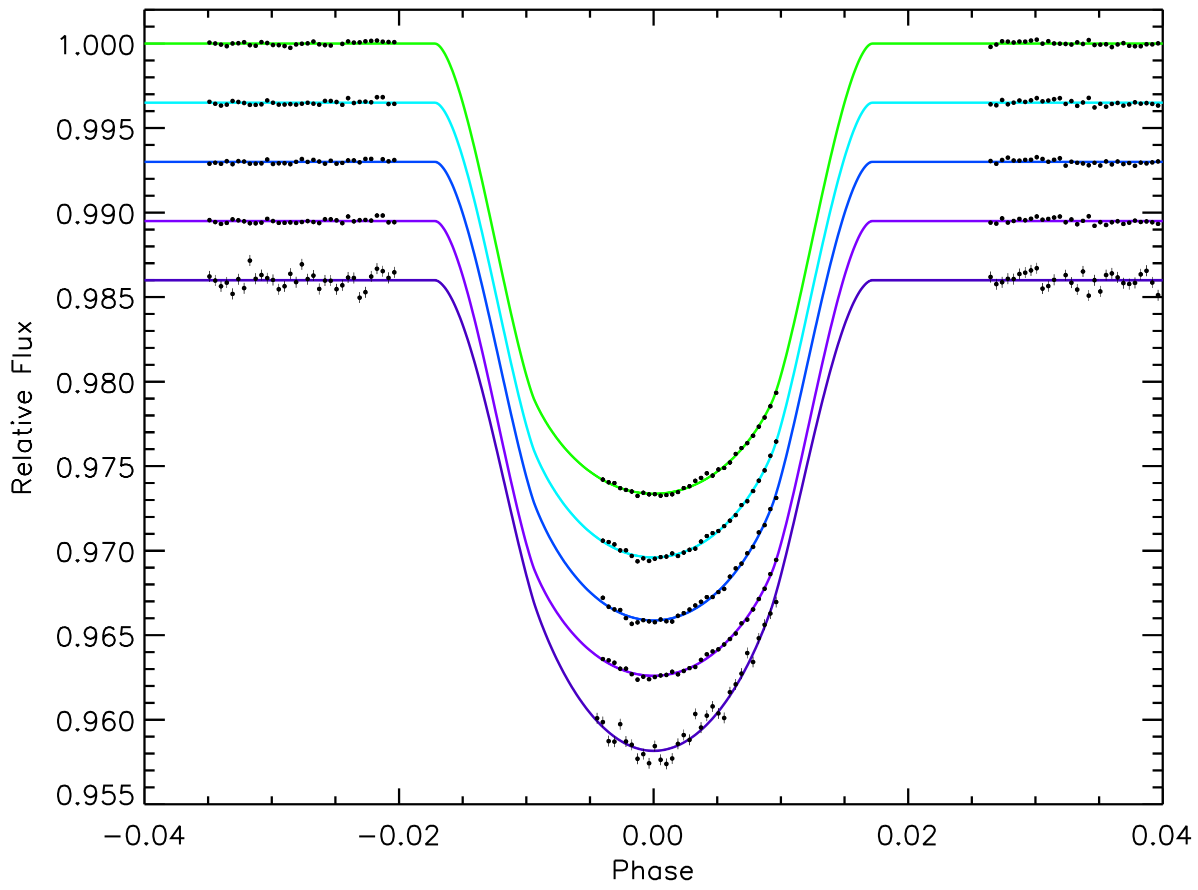


Figure Credit: Sing et al., 2011