Variable Noise Pixels
and pixel-level decorrelation

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IRAC Workshop, May 2014

This talk:

Noise sources at 3.6 and 4.5 microns

- a review of what you probably already know

Decorrelation methods

- traditional

- new: pixel-level decorrelation

- underlying assumptions

Noise due to the IRAC pixel sensitivity at 3.6 & 4.5 microns was known long before exoplanet observations:

$$Correction = 1 + 0.0535 \times \left[\frac{1}{\sqrt{2\pi}} - p \right]$$

(from the IRAC Instrument Handbook)

Exoplanet observations can't dither to average out the effect
Instead, hold a single position, and measure relative intensity changes to high precision

The telescope pointing oscillation + the intra-pixel effect leads to variable intensity

All methods to date implement corrections by defining and removing a correlation between image position and intensity fluctuations

Decorrelation methods:

Polynomials in Y and X (up to 4^{th} order, and XY sometimes)
(Charbonneau et al. 2005 and many others)

Spatial weighting functions (Ballard et al. 2010)

BLISS mapping – a fast spline interpolation
(Stevenson et al. 2012)

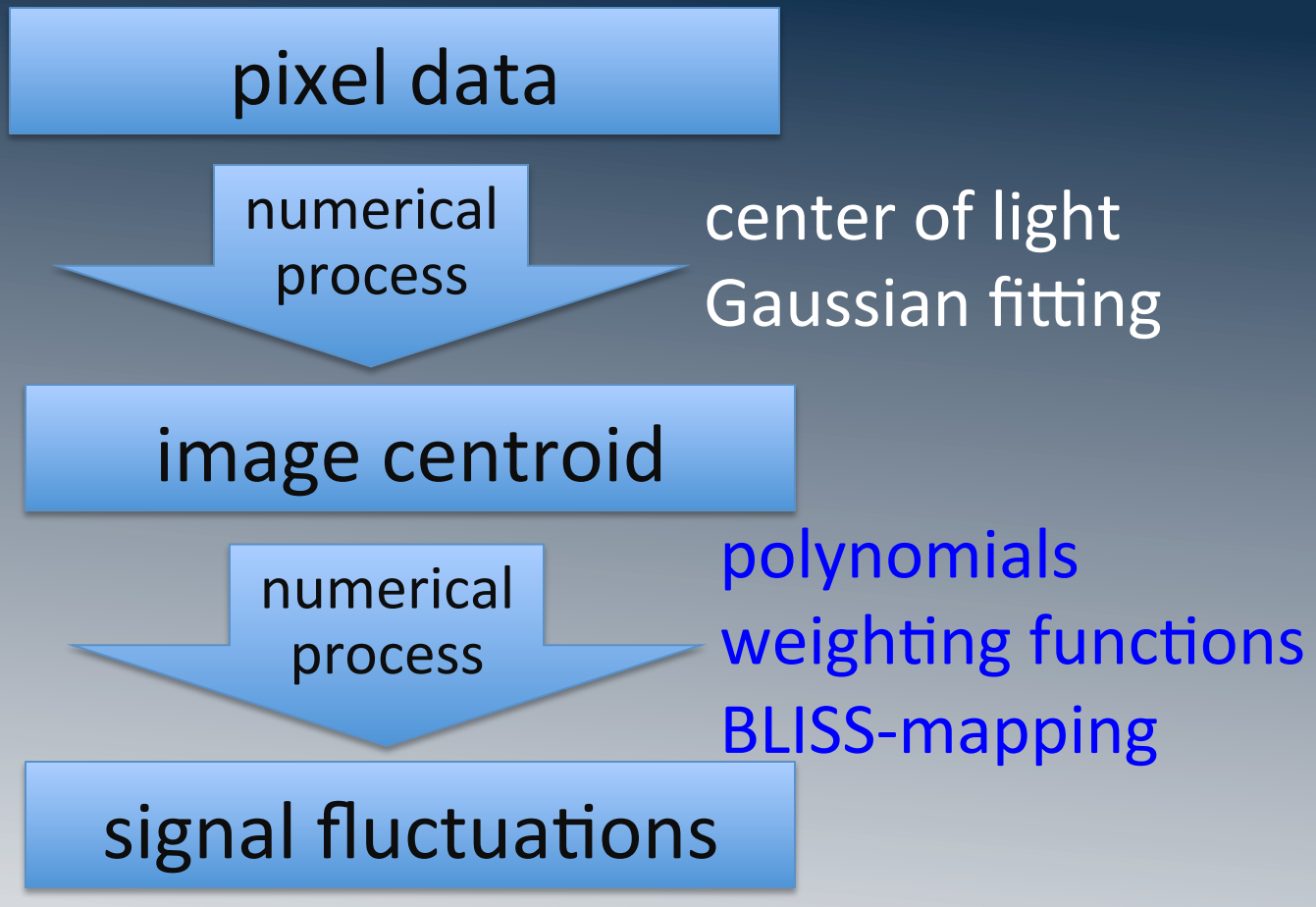
Variable-radius aperture photometry +
modified weighting function (Lewis et al. 2013)

Assumptions of spatial decorrelation methods:

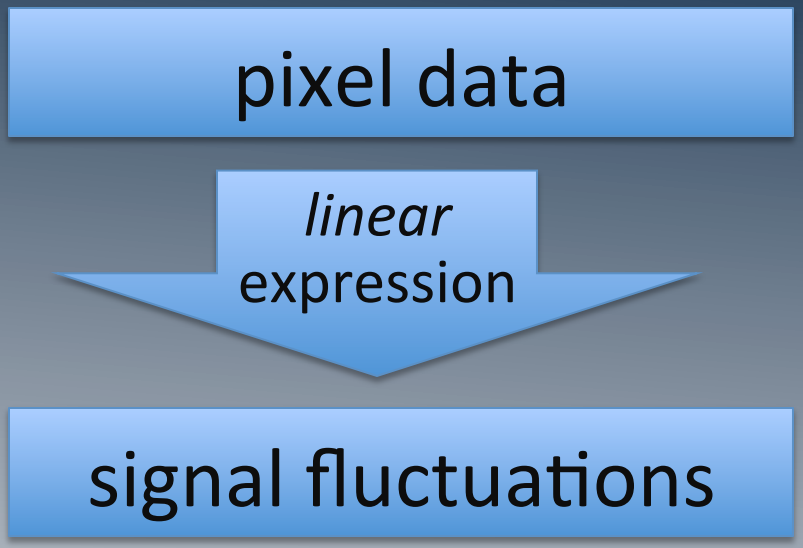
The detector pixel-to-pixel response does not vary with time

The image PSF is only displaced in X & Y, not distorted or rotated

All current decorrelation methods to date:



Pixel-level decorrelation:



the best way to remove effects of image motion is to *not use* the centroid or spatial coordinates of the image

Pixel-level decorrelation is:

Effective - little to no red noise

Simple - linear expression

Bayesian - MCMC compatible

Rigorous for small displacements

– coefficients follow from Taylor expansion

Fast – one multiplication per pixel

Objective – easily automated criteria

Tested – (we have a paper,
but only for eclipses, so far....)

Pixel-level decorrelation:

$$\hat{P}_i^t = \frac{P_i^t}{\sum_{i=1}^{N} P_i^t}$$

i = pixel index
t = time step
3 x 3 box of pixels

normalizes the pixels
(removes all astrophysical effects)

Pixel-level decorrelation:

$$\delta S^t = \sum_{i=1}^{N} c_i \hat{P}_i^t + \text{eclipse model} + \text{ramp}$$

solve for the c_i with linear regression
explore parameter space with MCMC

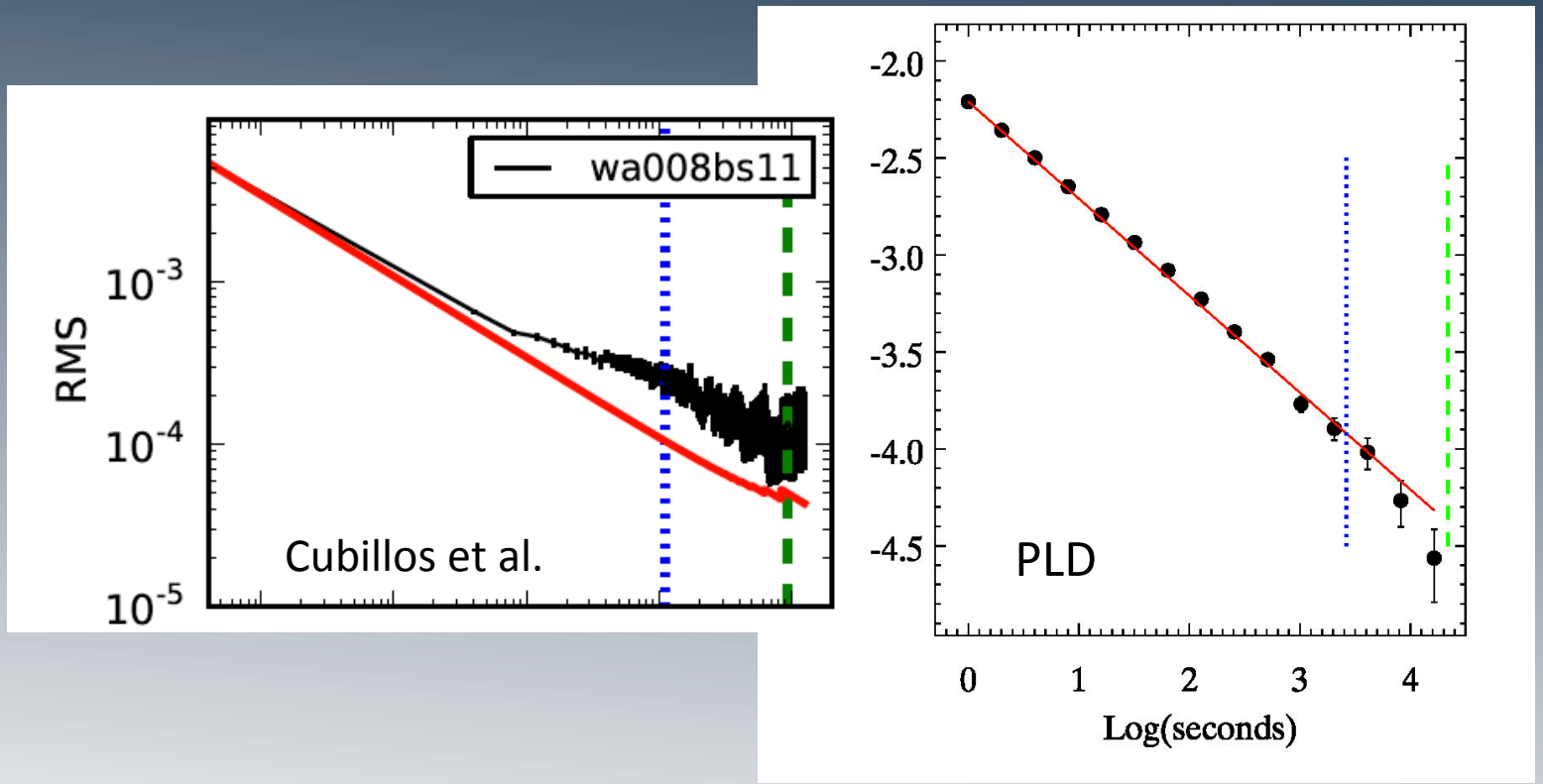
Pixel-level decorrelation assumes:

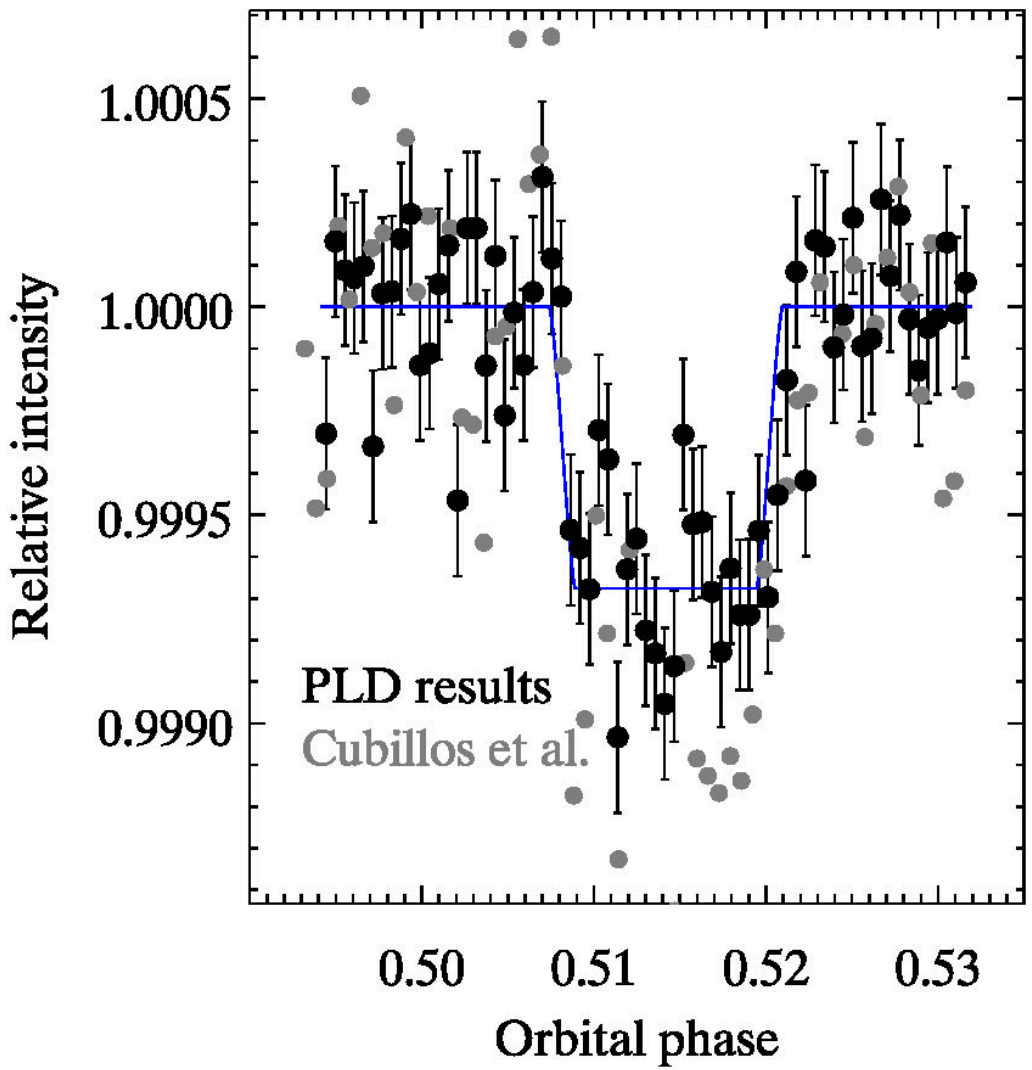
The detector pixel-to-pixel response does not change with time

Changes in the image PSF are OK
(I think, because there's no explicit X-Y dependence)

Example: WASP-8b

Cubillos et al. (2014) ApJ 768, id.42




1.0005
1.0000
0.9995
0.9990
Relative intensity
PLD results
Cubillos et al.
0.50
0.51
0.52
0.53
Orbital phase

Summary:

Intrapixel noise at 3.6 & 4.5 microns

is conventionally removed by explicitly defining and removing its spatial dependence

Those methods are mostly successful

but sometimes leave red noise

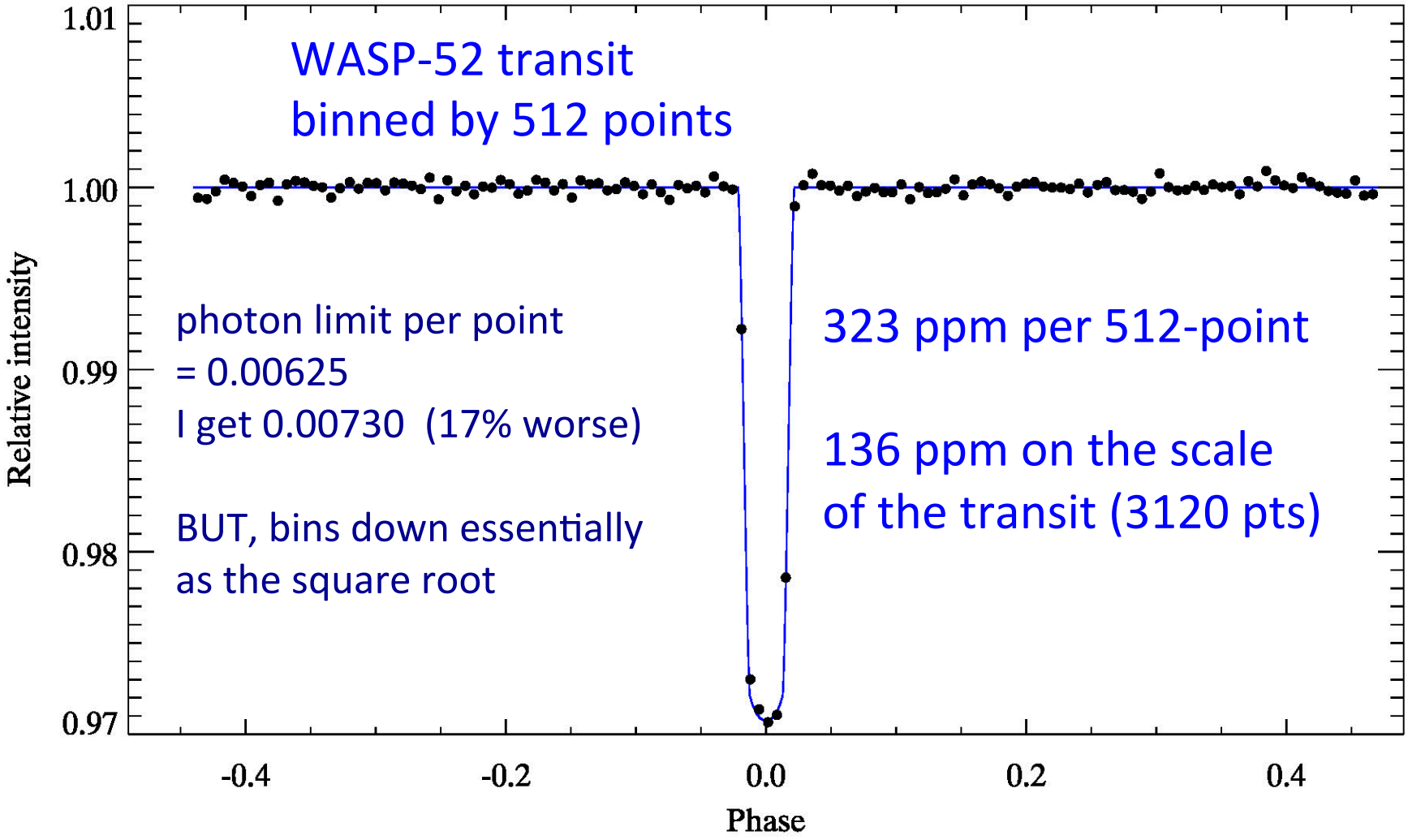
Pixel-level Decorrelation (PLD)

- doesn't use the position of the image

- very effective at removing red noise

- not applied to phase curves (yet)

We should re-analyze all of the exoplanet eclipses using PLD


WASP-52 transit
binned by 512 points
photon limit per point
= 0.00625
I get 0.00730 (17% worse)
BUT, bins down essentially
as the square root
323 ppm per 512-point
136 ppm on the scale
of the transit (3120 pts)
Relative intensity
1.01
1.00
0.99
0.98
0.97
-0.4
-0.2
0.0
0.2
0.4
Phase