Lessons Learned from Real Data

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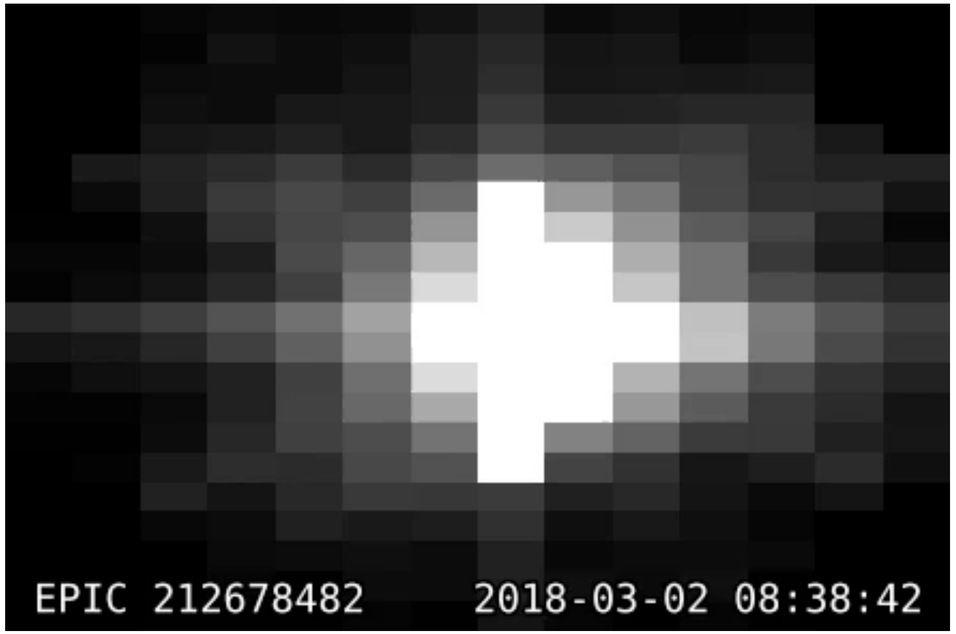
Our job sounds easy — count up all the flux from the target, and none of the flux that isn't from the target

But this is actually hard!! Because of …

- Pointing variations
- Pixel sensitivity variation — in space and over time
- Loss of light
- Accurate background subtraction
- Badly behaved pixels
- Cosmic rays
- Undersampling
- Foreground objects
- Contamination from background stars
- Geometric distortion

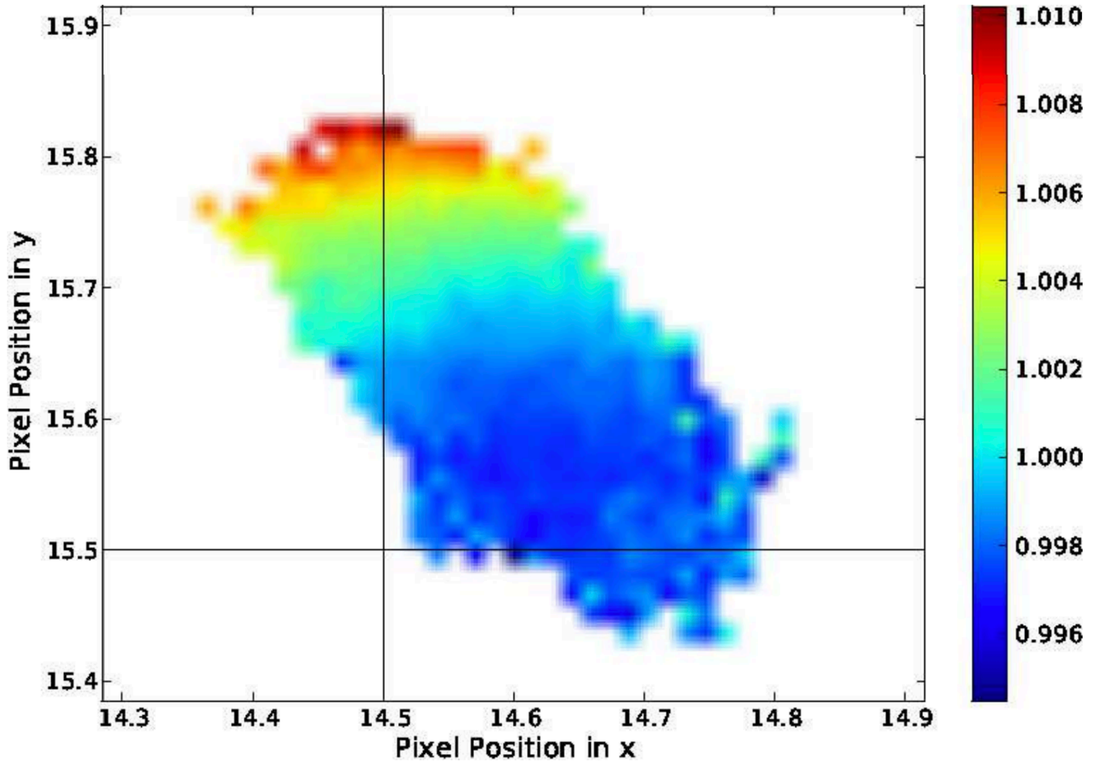
Pointing jitter



Two-month animation of K2 pixel data

— **K2flix (https://barentsen.github.io/k2flix/)**

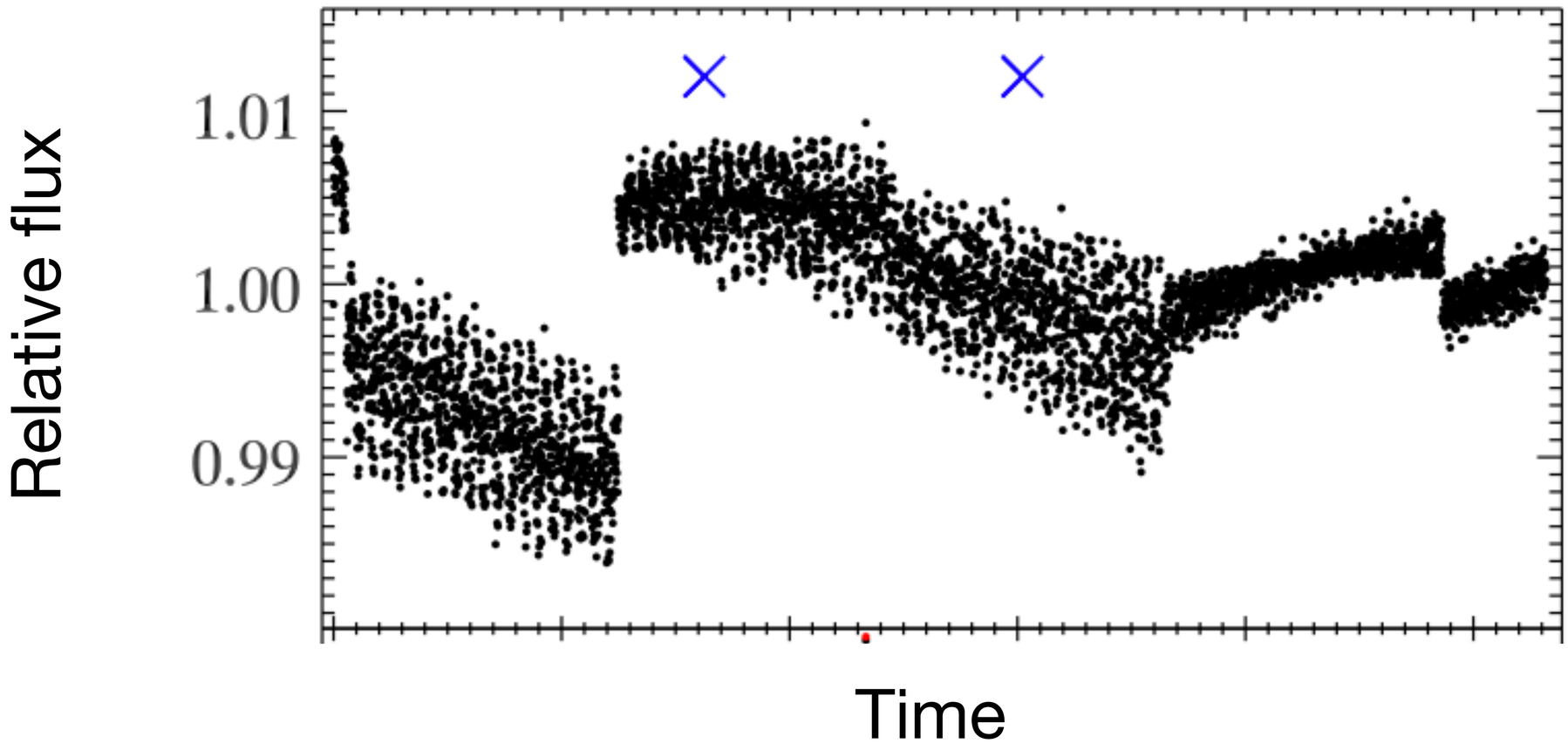
Pixel sensitivity variations



Stevenson et al. 2012

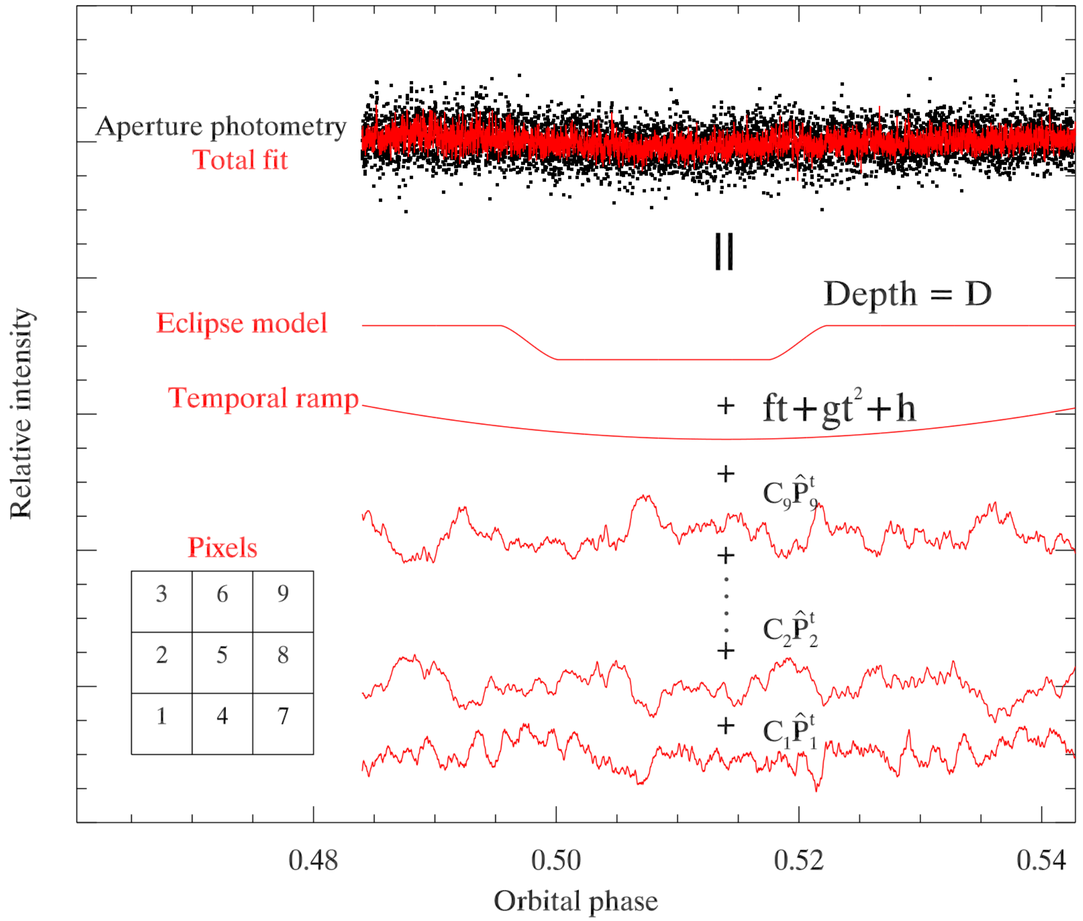
Spitzer IRAC sensitivity varies by >1% over a single pixel

Pointing jitter + sensitivity variations =



Deming et al. 2015

Lessons learned

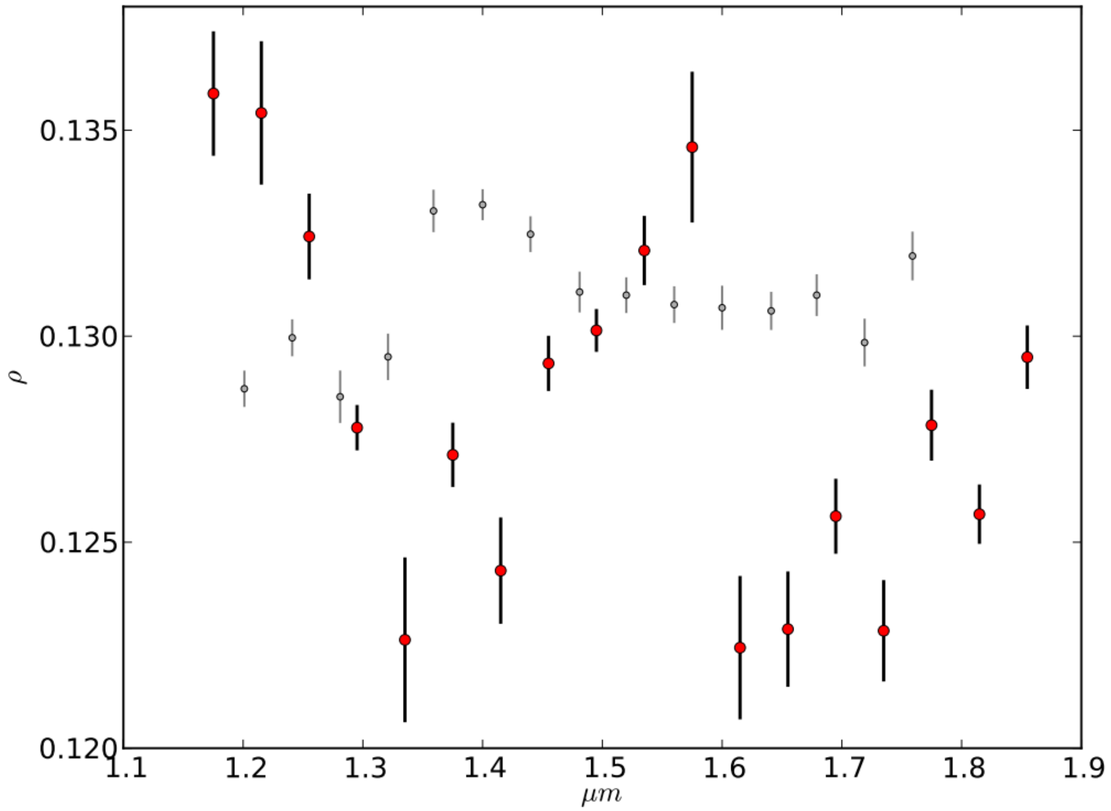


Deming et al. 2014 — Pixel-Level Decorrelation

Can correct for this effect by simultaneously modelling pixel sensitivity and astrophysical signal (see Ingalls et al. 2016 for a review)

But these methods work best for photometry with lots of data points (e.g. Spitzer, TESS)

Lessons learned

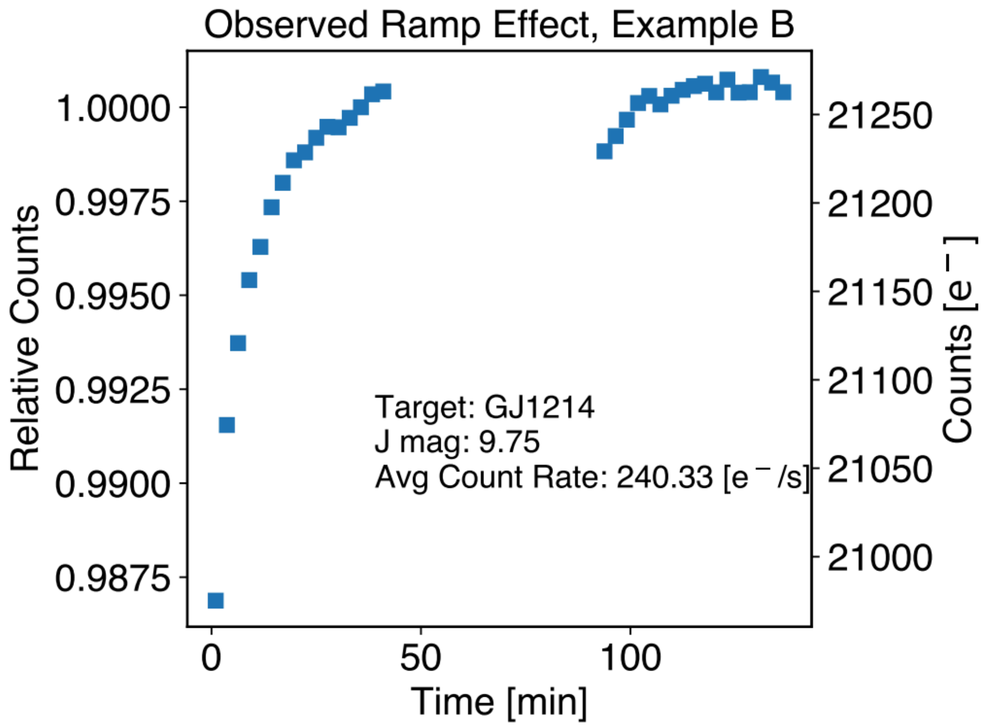


Caution!!

Pixel sensitivity correction does not work as well for spectroscopy as it does for photometry

Gibson et al. 2011 — NICMOS transmission spectrum from two different instrument systematics models

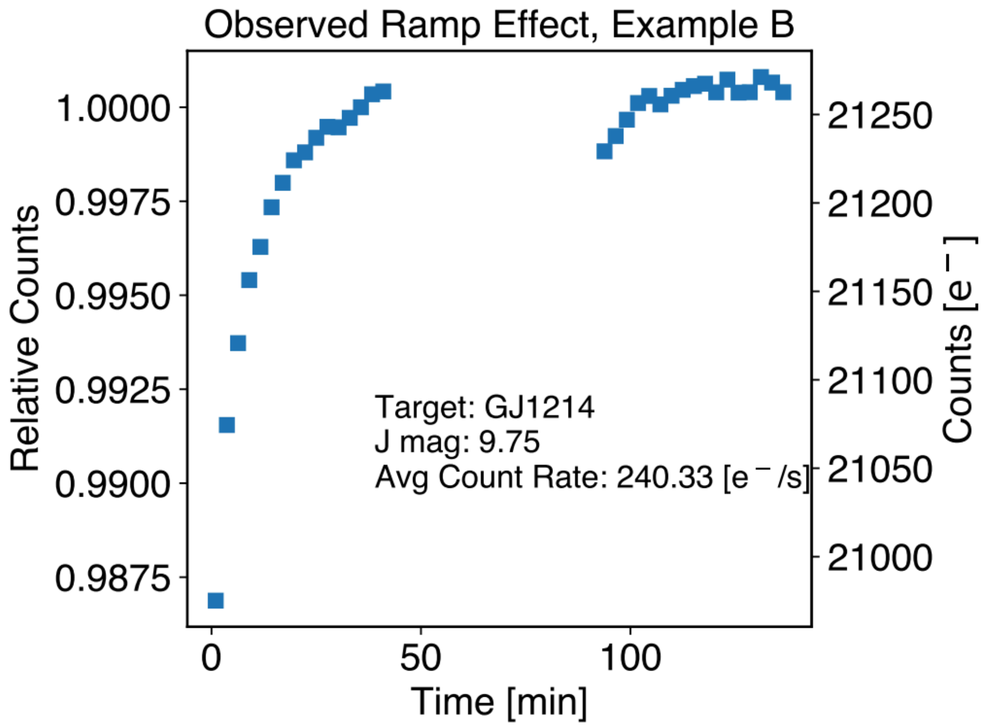
Time-dependent sensitivity variations



Zhou et al. 2017

Charge traps in the detector fill up as it is exposed to high photon count rates, leading to ramp-like systematics in the time series

Lessons learned



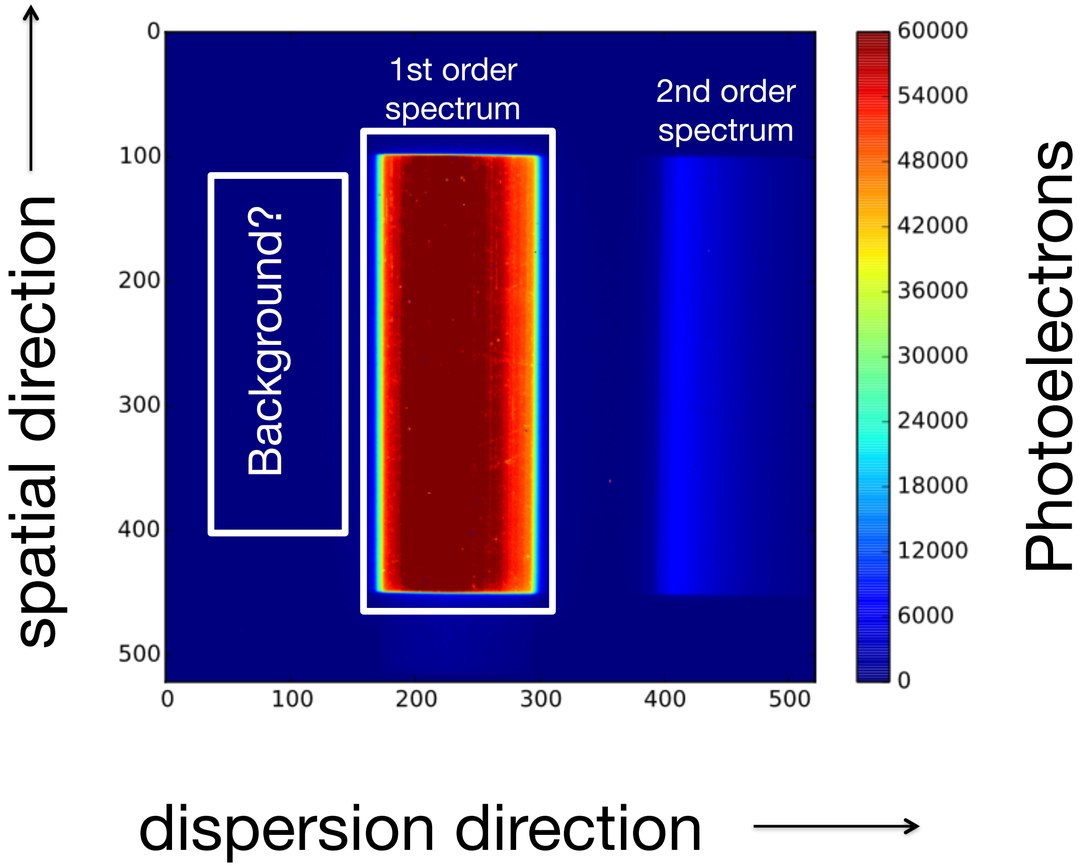
Zhou et al. 2017

Ramp effects can be successfully modelled (both analytic and nonparametric models work fairly well)

The first hour of data collection will be most strongly affected by charge trapping

Loss of light and background subtraction

Where should the extraction window be? Where should we estimate the background?



Hubble Wide Field Camera 3 observations of 55 Cancri e (PI: Dragomir)

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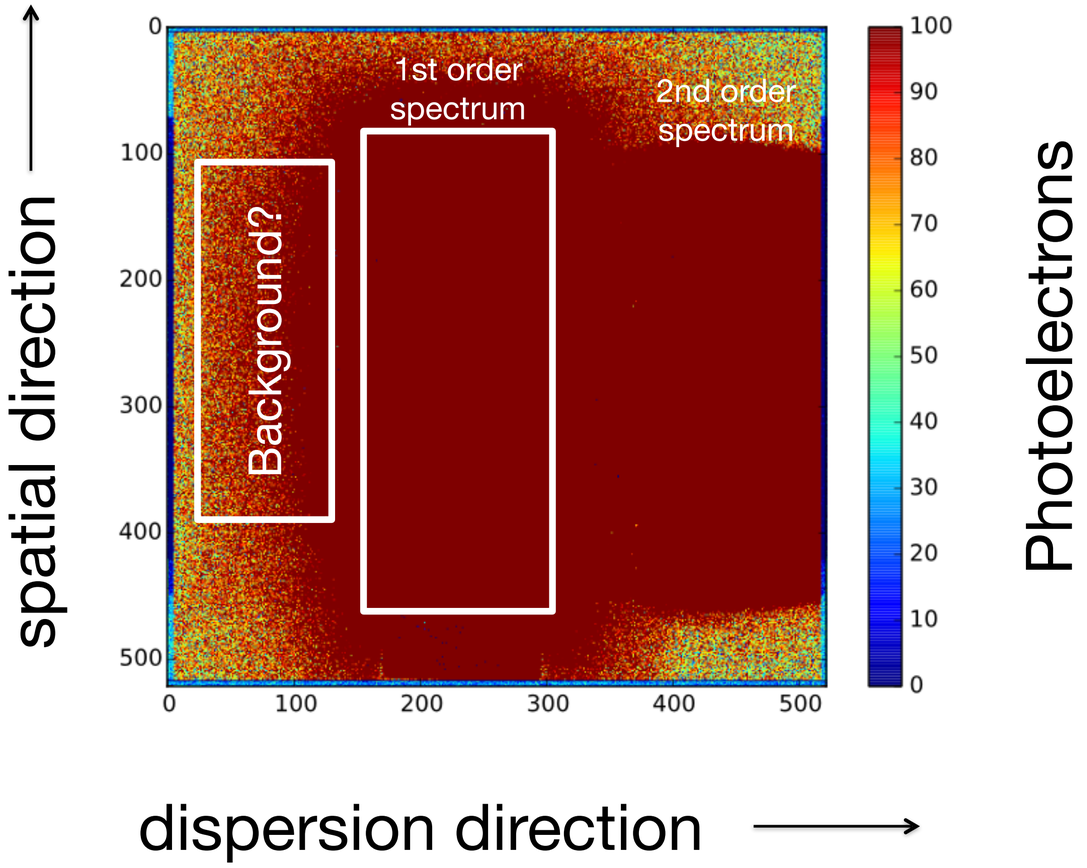
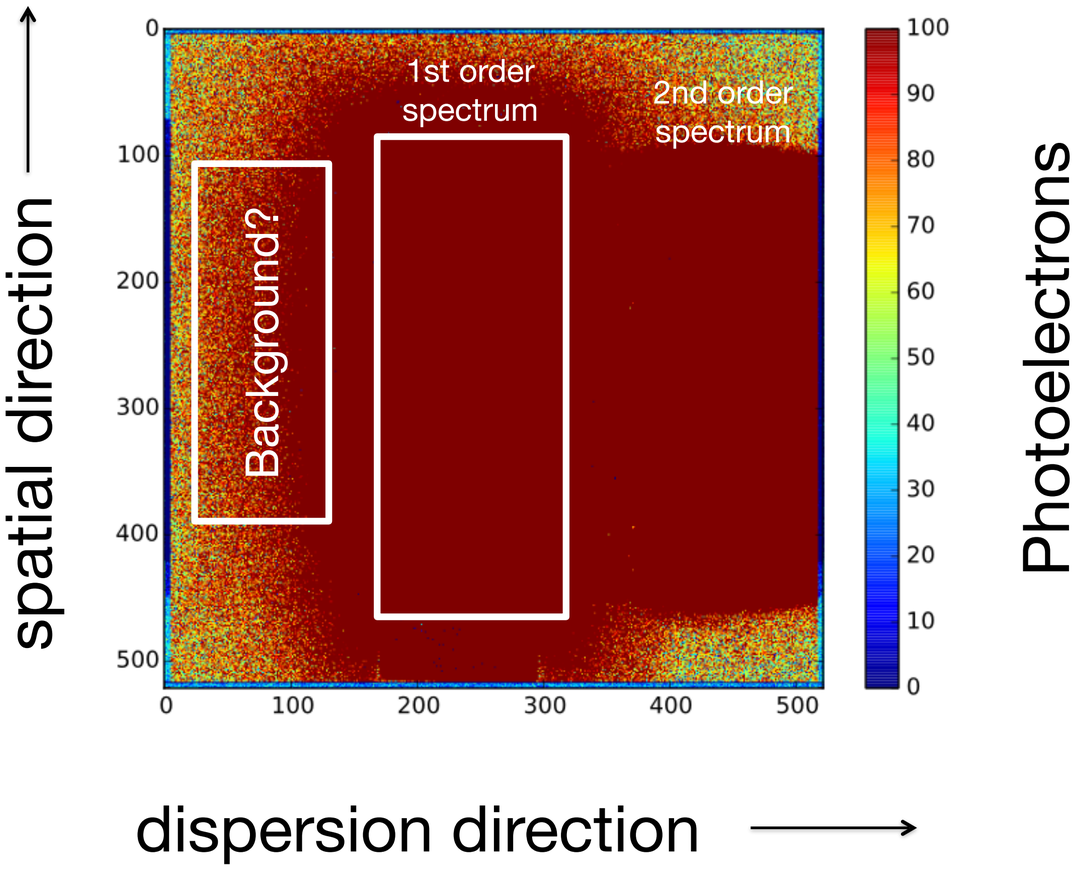


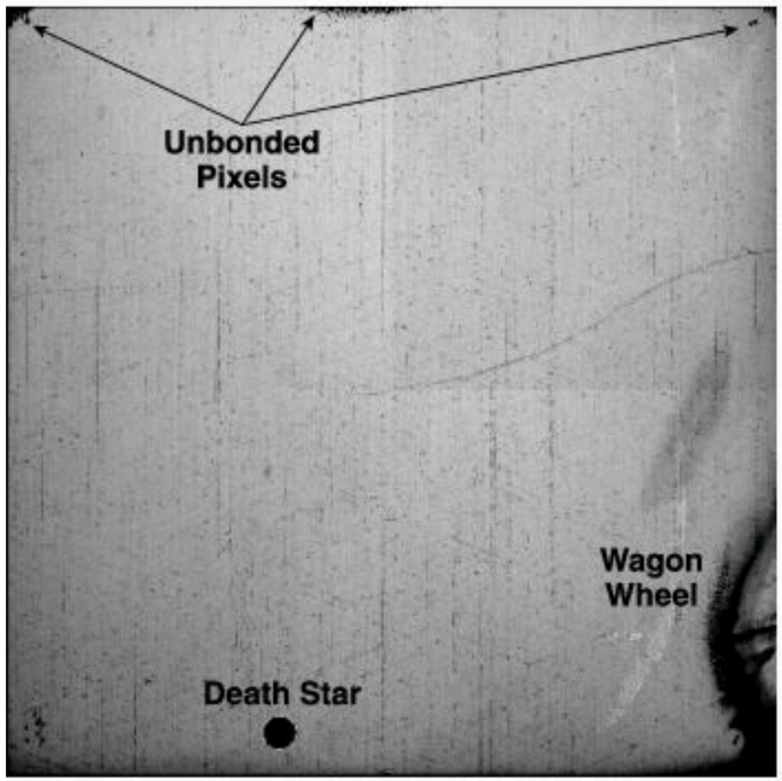
Hubble Wide Field Camera 3 observations of 55 Cancri e (PI: Dragomir)

Lessons learned

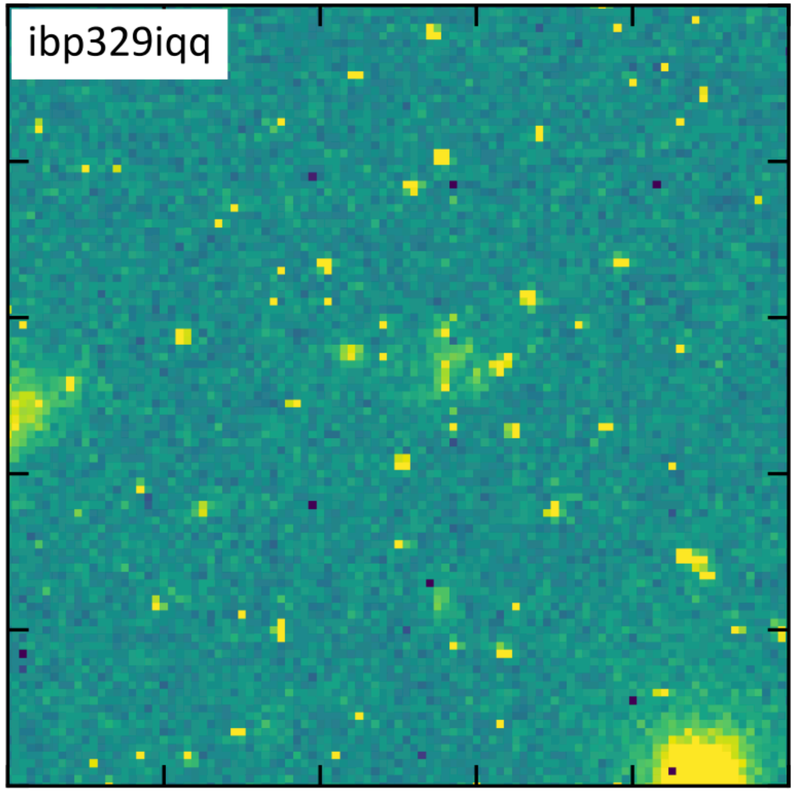


- If possible, design the observation with lots of space around the target spectrum
- Test a wide range of extraction windows
- Background subtraction can be a noise floor for the most extreme cases

Badly behaved pixels and cosmic rays

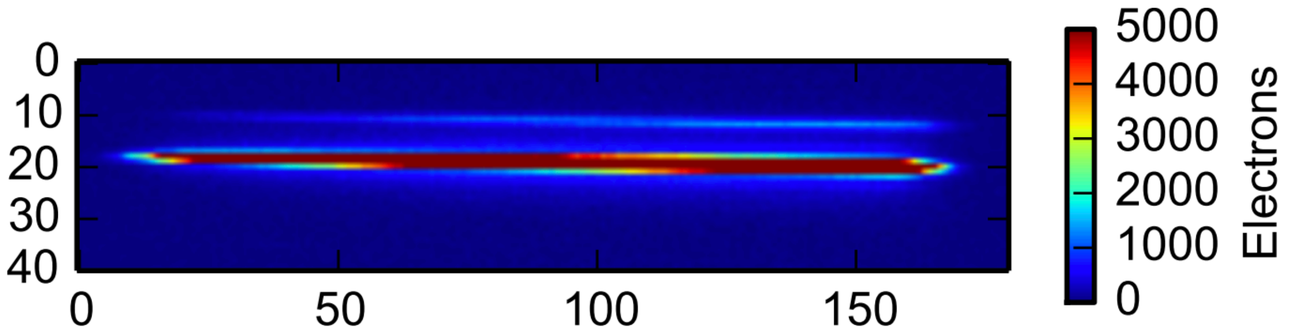


HST/WFC3 detector cosmetics
(Instrument Handbook)



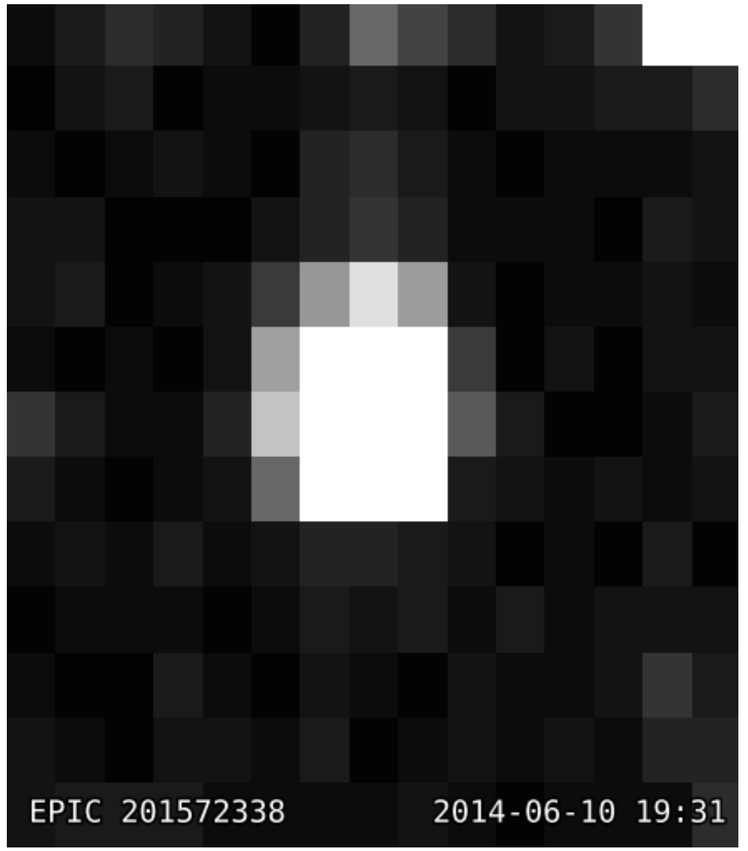
HST/WFC3 cosmic rays
(WFC3 ISR 2016-16)

Contamination



Background star near WASP-12

(Kreidberg et al. 2015)

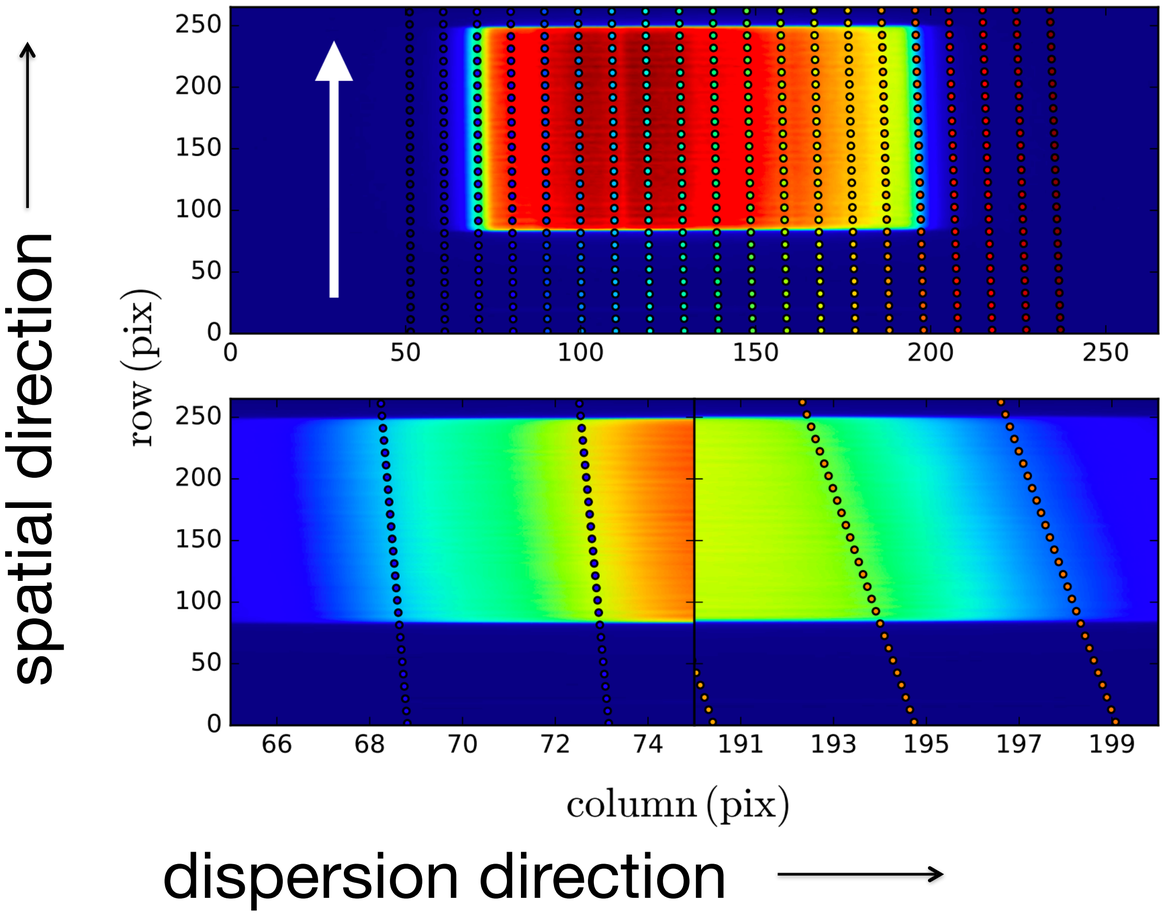


Foreground asteroids in K2 data!

(k2flix)

Geometric distortion

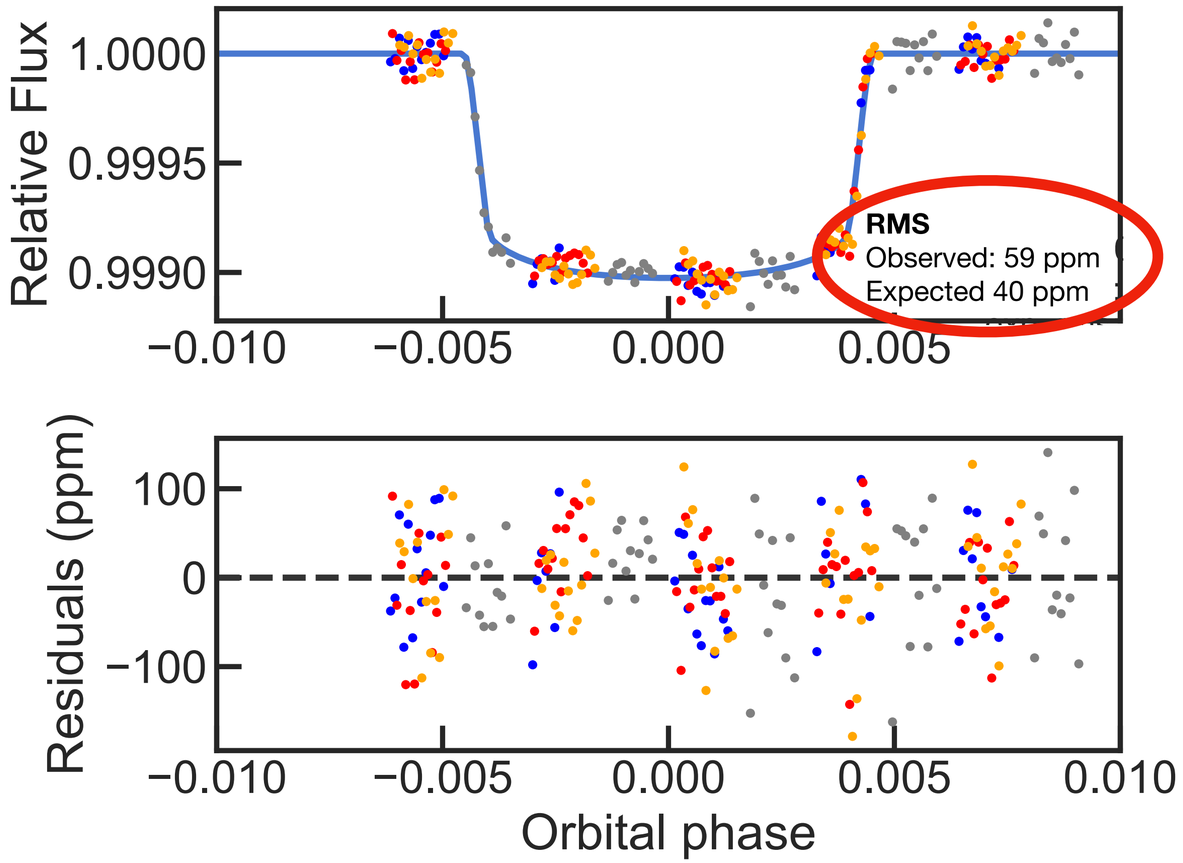
Dispersion solution changes along the detector



Tsiaras et al. 2016

How do I know if I got it right?

Check the photon noise! Beware of unknown unknowns!



Stars emit $N \pm \sqrt{N}$ photons per unit time. The $\sqrt{N}$ noise, so-called **photon noise**, arises because each atom in the star emits a photon with some small probability per unit time, so the count rate follows a Poisson distribution. Photon noise is the fundamental limit on the precision of a light curve.

— Handbook of Exoplanets, 2018 (eds. Deeg and Belmonte)