# Direct measurement of *Kepler's* intra-pixel response function

Dmitry Vorobiev[a,b], Zoran Ninkov[a], Alexis Irwin[a], and Kevan Donlon[a]
[a]Rochester Institute of Technology, [b]Laboratory for Atmospheric and Space Physics, CU Boulder

## Introduction

Stellar images recorded by Kepler's CCDs are under-sampled. This results in increased photometric and astrometric uncertainty in Kepler and K2 observations. We used the spot scanning technique to directly measure the intra-pixel response function of a flight spare CCD (SN 208), which was made for the Kepler mission.

- Kepler's pixels are 27 μm with plate scale of 3.98'' per pixel.
- The central pixel can contain up to 50% of the energy (Brightest Pixel Flux Fraction < 0.5), which indicates a full width at half maximum (FWHM) of less than 2 pixels.
- The PSF of the telescope can have spikes and other components of high spatial frequency.

## Measurement Setup

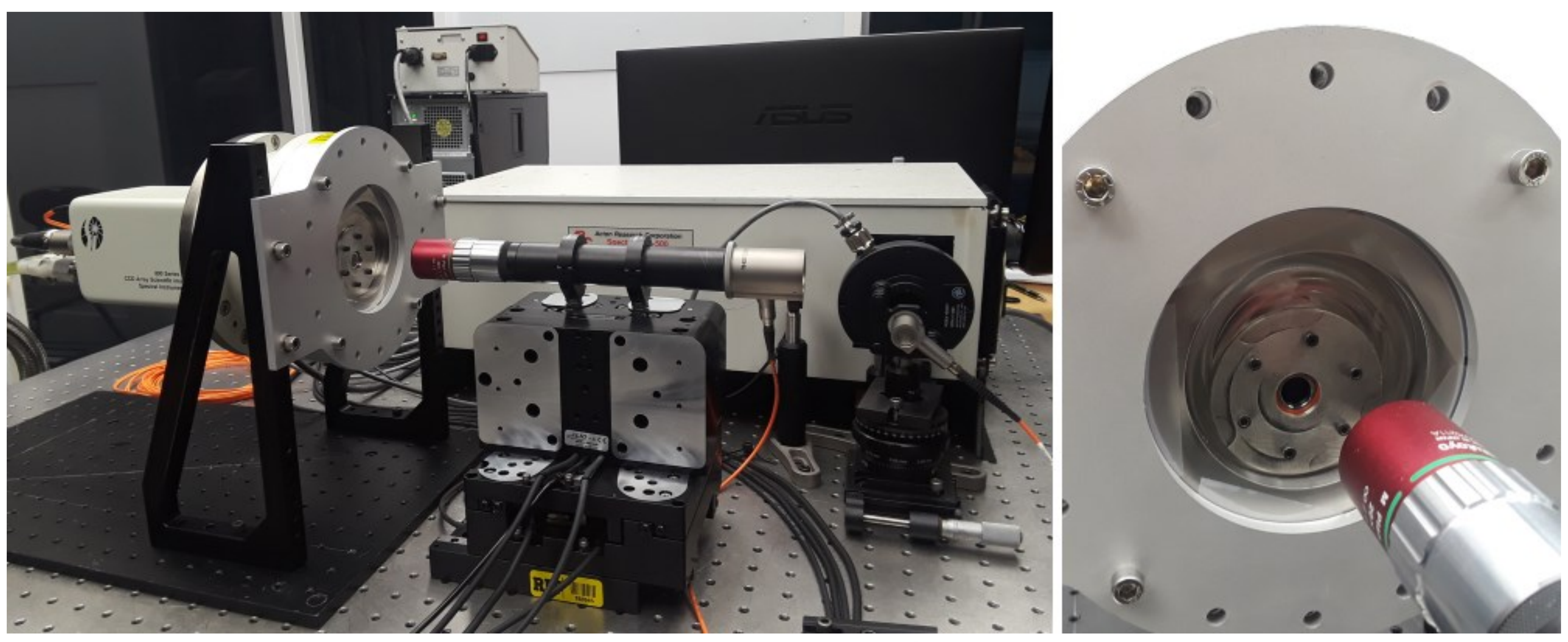


Figure 1. Spot scanner built at RIT (Left). Measurements are made through a 10 mm diameter, 500 um thick fused silica window (Right).

- A spot projector generates spots with FWHM ~ 2 - 3 um
- Spectral range 400 - 900 nm, Δλ ~ 10 nm
- An XYZ translation system moves the spot projector with a bidirectional repeatability of 20 nm
- Our lab's foundation is vibrationally isolated
- CCD is housed in a SI 800 cooled camera (-45° C)

## Spot Characterization

The size of the projected spot was measured using a Canon 120MXS CMOS sensor with 2.2 μm pixels. The spot profile was measured by scanning the spot across a single pixel, in 100 nm increments. Measurements were made at 400*, 450, 500, 550*, 600, 650, 700*, 750, 800 and 850 nm. *A second set of measurements was made at these wavelengths, through a 500 um thick window, which is identical to the window used with the SI 800 camera (Fig 1). To infer the actual spot size, models of the spot shape were fit to the measured profiles (using several pixel response models for the 120MXS sensor).

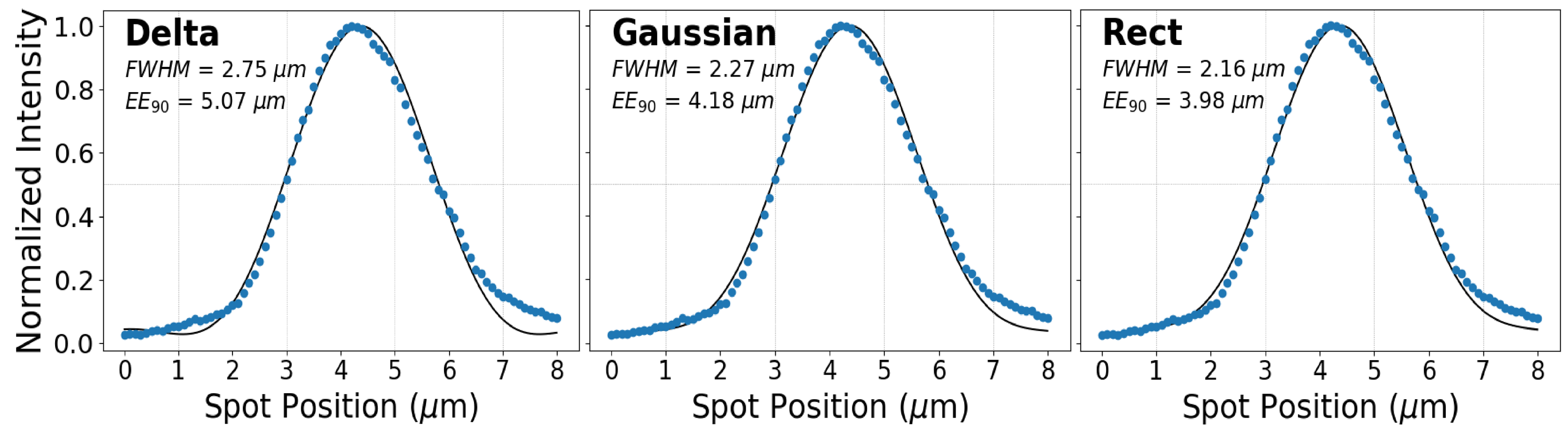



Figure 2. The measured intensity profiles and best fit spot models for measurements at 700 nm, with the 500 μm window in place.

- By modeling the pixel response function (PRF) of the 120MXS pixels, we estimate the intrinsic size of the spot.
- The **Gaussian** PRF describes a decrease in response of ~50% at the edges of the pixel.
- The **Delta** and **Rect** (uniform) PRFs are the upper and lower limits on the spot size estimate, respectively.

## *Kepler's* Intra-Pixel Response

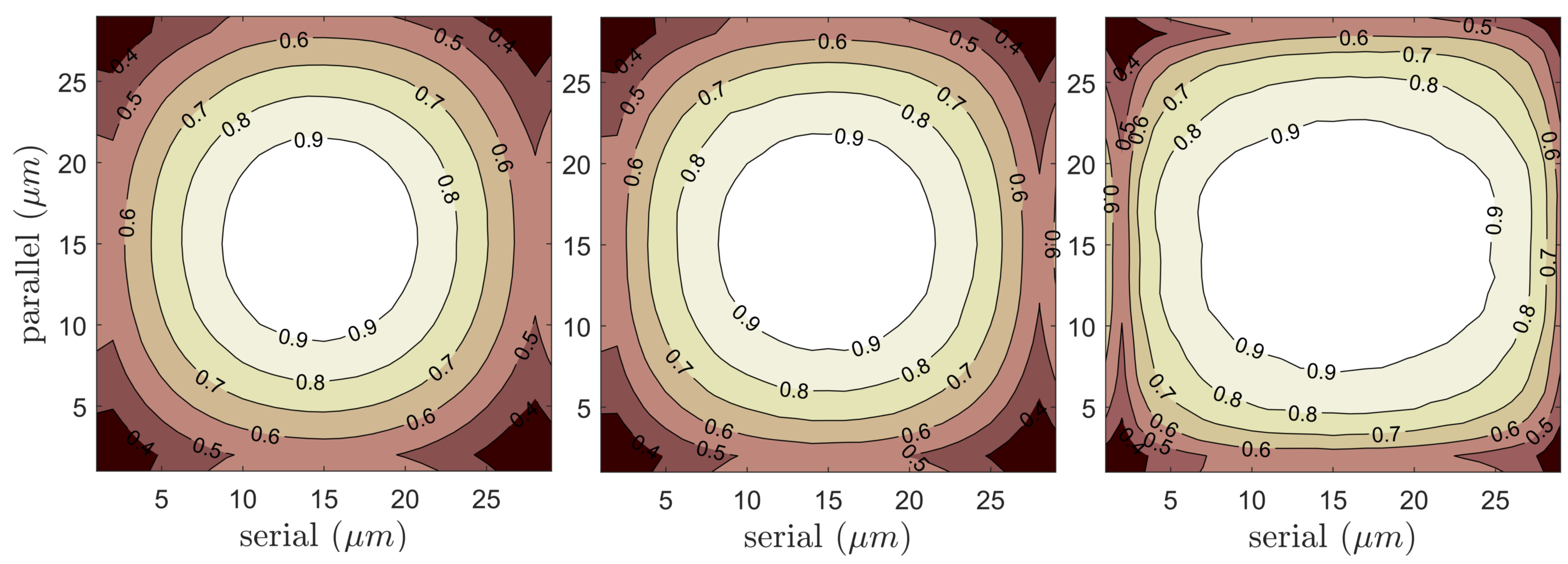
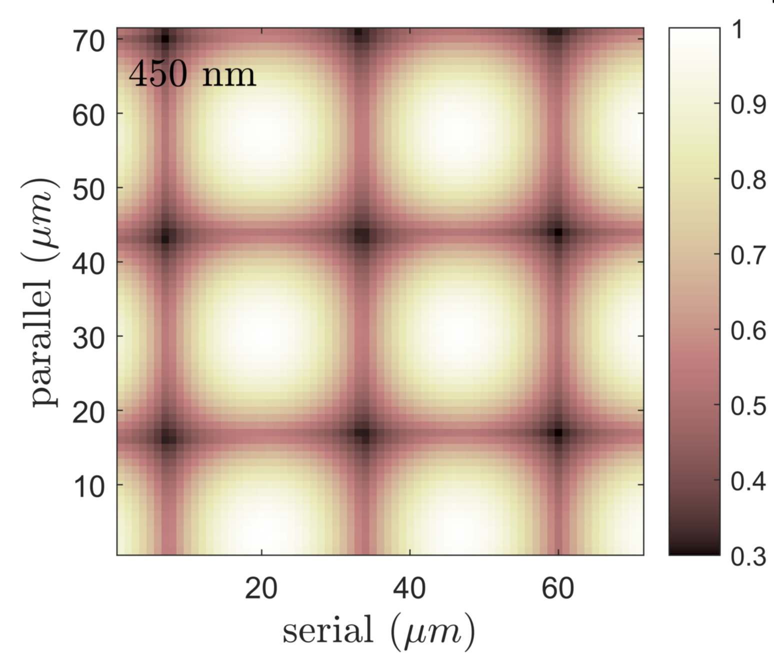
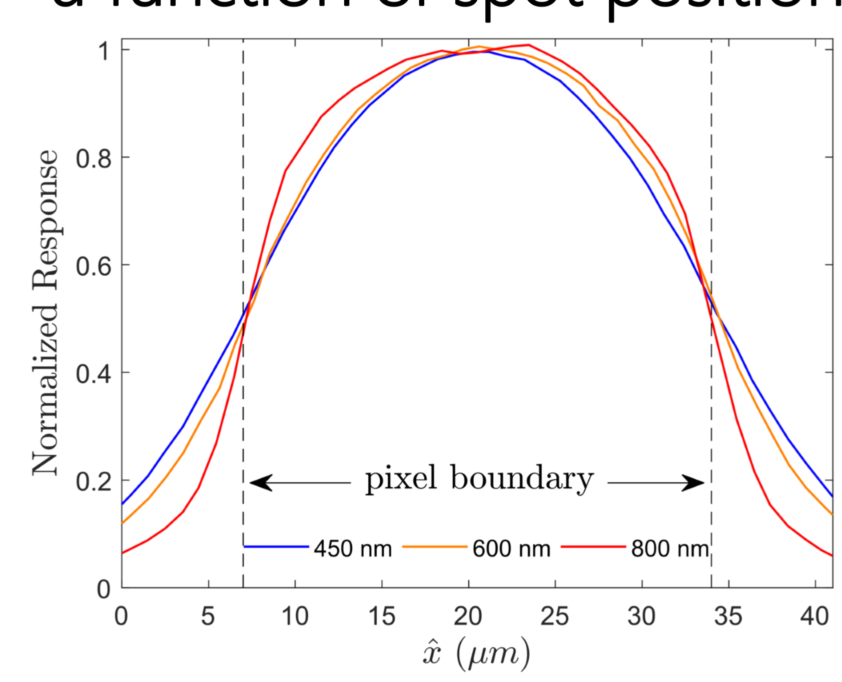



Figure 3. Normalized response of the Kepler CCD as a function of spot position, for 450 nm, 600 nm, and 800 nm. Spot step size is 1 um.

A typical scan area:
70 um × 70 um, 1 um step




Response of a single pixel, as a function of spot position.




Shown here is Kepler's raw pixel response;
effects due to spot size have not yet been removed.

## Conclusions

Our initial data show that our system is very stable and can operate over Kepler's entire passband. Kepler's detectors show an IPRF similar to other back-illuminated devices: smoothly varying at shorter wavelengths and more defined by the gate structure at longer wavelengths. Our goal is to measure the multiwavelength IPRF and incorporate it into the Kepler pipeline.

Acknowledgements: this research is supported by NASA ADAP grant NNX16AF43G. We thank J. Hoover for significantly improving the stability of the data acquisition software.