Dynamic Black-Level Correction and Artifact Flagging in the *Kepler* Data Pipeline

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Abstract

Instrument-induced artifacts in the raw *Kepler* pixel data include time-varying crosstalk from the fine guidance sensor (FGS) clock signals, manifestations of drifting moiré pattern as locally correlated non-stationary noise and rolling bands in the images which find their way into the calibrated pixel time series and ultimately into the calibrated target flux time series. Using a combination of raw science pixel data, full frame images, reverse-clocked pixel data and ancillary temperature data the *Kepler* pipeline models and removes the FGS crosstalk artifacts by dynamically adjusting the black level correction. By examining the residuals to the model fits, the pipeline detects and flags spatial regions and time intervals of strong time-varying black-level (rolling bands) on a per row per cadence basis. These flags are made available to downstream users of the data since the uncorrected rolling band artifacts could complicate processing or lead to misinterpretation of instrument behavior as stellar. This model fitting and artifact flagging is performed within a new stand-alone pipeline module called Dynablack.

We discuss the implementation of Dynablack in the Kepler data pipeline and present results regarding the improvement in calibrated pixels and the expected improvement in cotrending performance as a result of including FGS corrections in the calibration. We also discuss the effectiveness of the rolling band flagging for downstream users and illustrate with some affected light curves.

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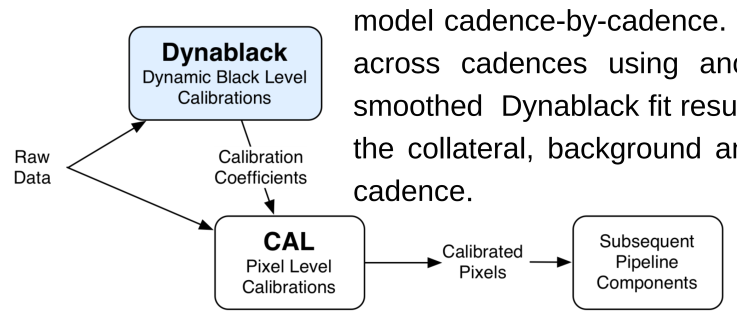
Dynamic Black-Level Correction - Dynablack

Pipeline Data Flow

The pipeline component Dynablack performs black level calibration in a two-step process. Input pixel data are fit to a multi-component model cadence-by-cadence. Then the resulting fit coefficients are fit across cadences using ancillary temperature data. CAL uses smoothed Dynablack fit results to perform black level corrections on the collateral, background and target pixels for each long or short cadence.

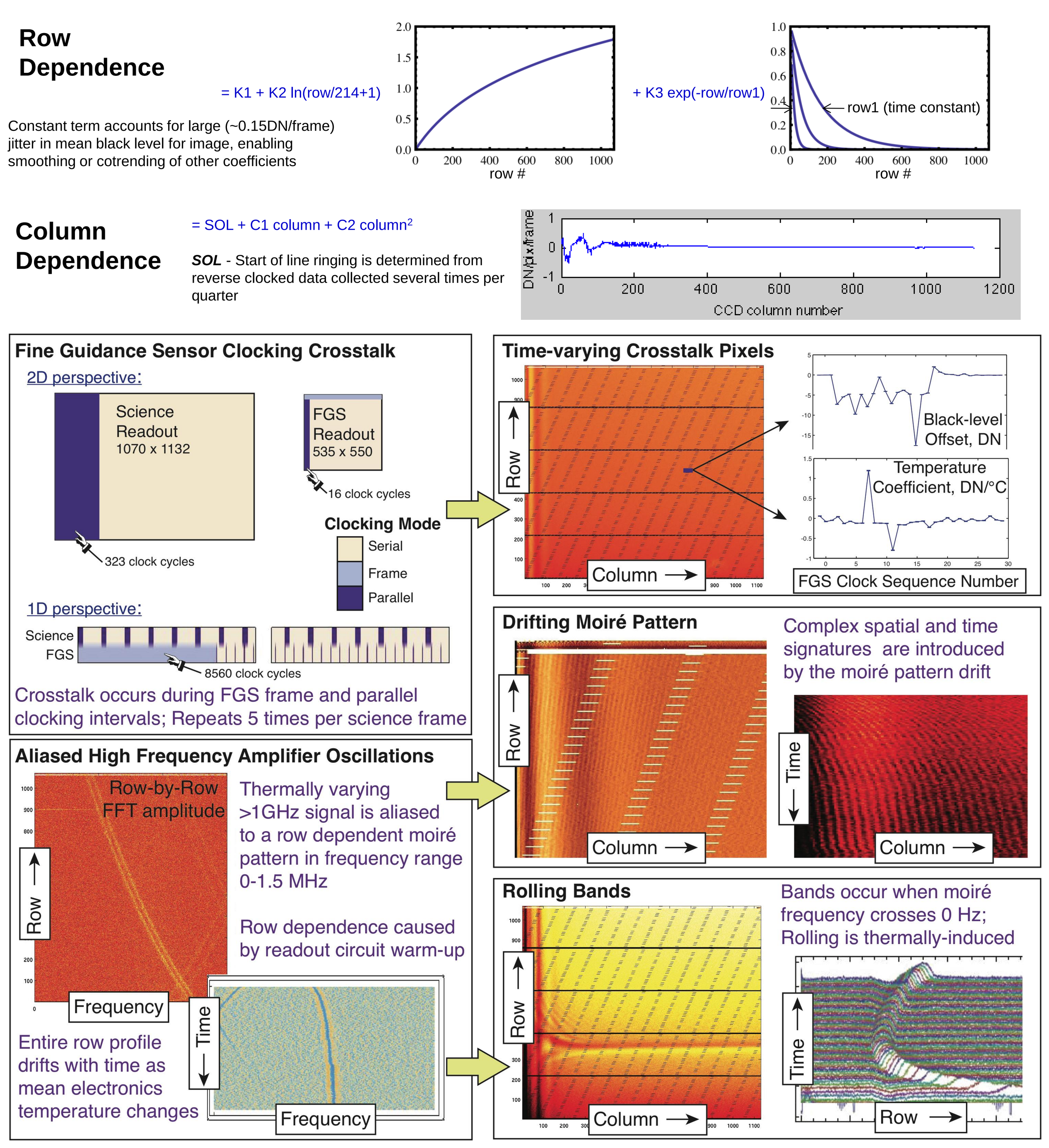


Dynamic Black Level Model Components

Time interval	Component	Baseline	Dynablack
Cadence-by-Cadence	Row Dependence	x	x
	Column Dependence		x
	Parallel FGS cross-talk		x
	Frame FGS cross-talk		x
	Moire Pattern – Rolling Bands		Monitored
	Undershoot		Monitored
Across Cadences	Time Dependence		x
	Temperature Dependence		x

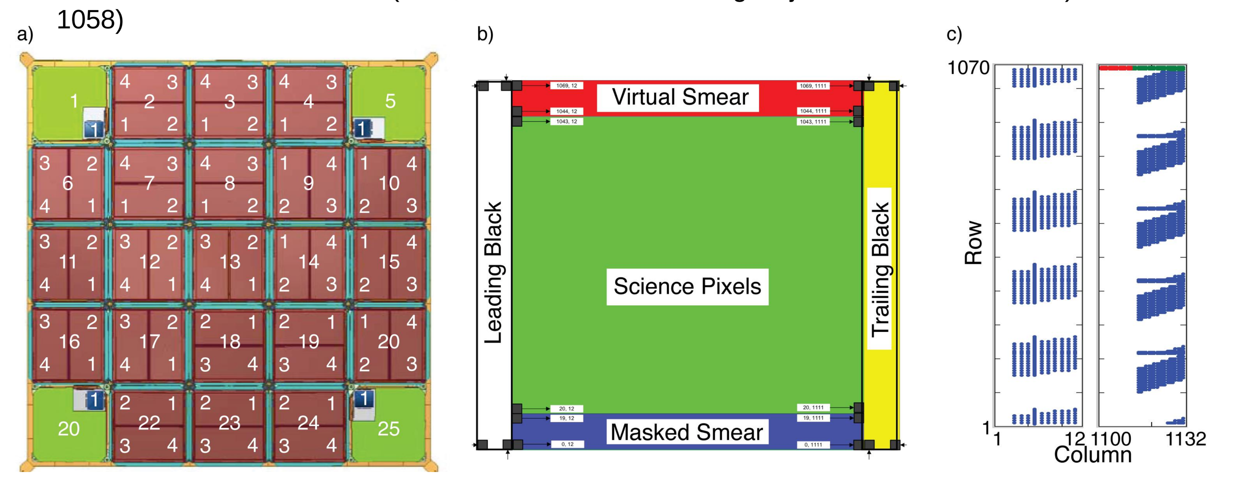
All terms in the baseline CAL black-level model were static except for the row dependence. Dynablack now enables more complete modeling and accounts for cross-cadence time and temperature trends, as well as monitoring of moiré pattern and undershoot.

Black-Level Model Component Descriptions



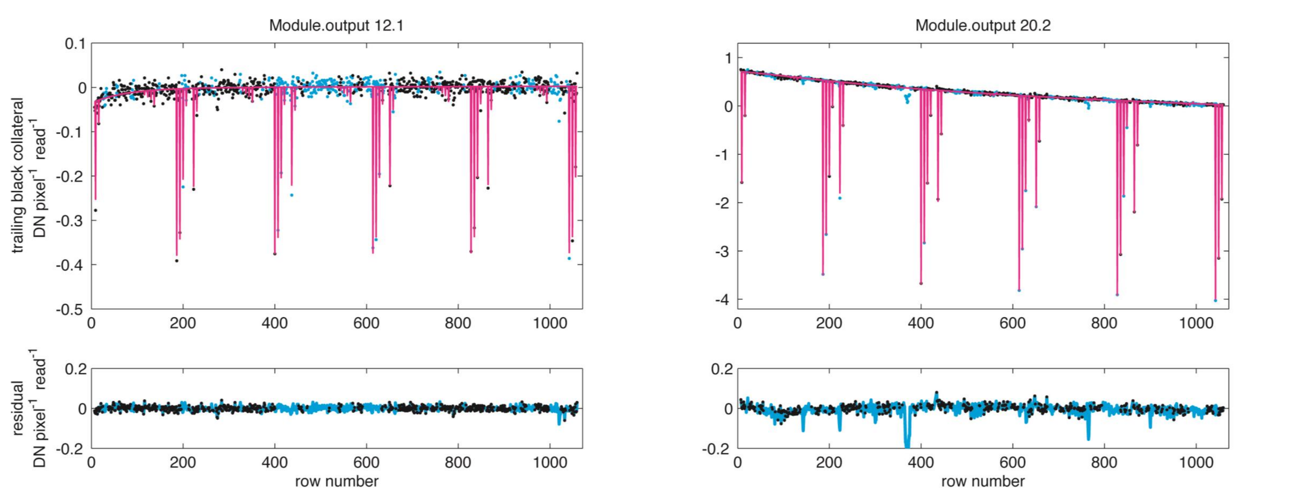
Dynablack Input Data

- **Full Frame Images** collected 3 times per quarter
- **Reverse-clocked long cadences** collected 3 times per quarter
- **Collateral Data** with each long cadence
  - Trailing Black (Virtual Columns) - summed across 14 columns (1119-1132)
  - Masked and Virtual Smear (Rows) - summed over 12 rows each (7-18, 1047-1058)
- **Artifact Removal Pixels** (ARPs) with each long cadence
  - Cover time-varying FGS crosstalk
  - Also permit undershoot measurement following charge injection rows 1060-1063)



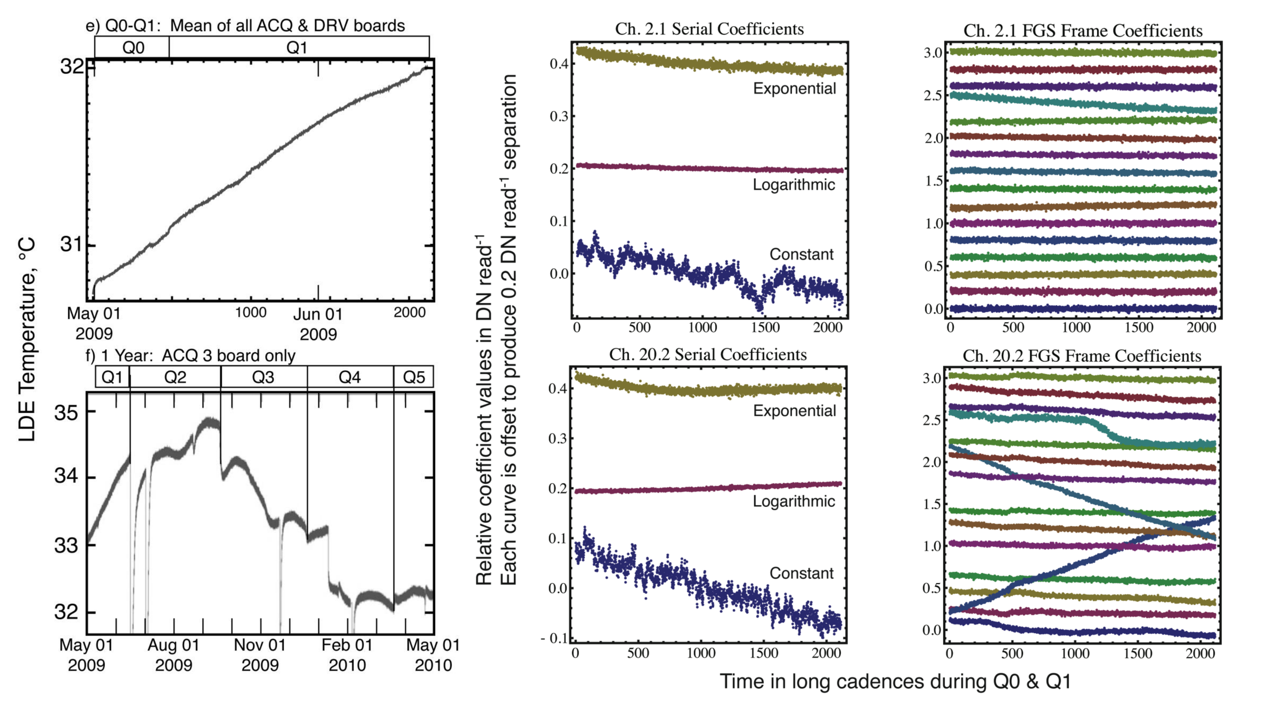
Fitting for Cadence-by-Cadence Black Level Model Coefficients

Below are the fitted curves (red) and raw data (black) for trailing black collateral in channels 12.1 and 20.2 for one representative Q1 long cadence. The residuals are < 0.02 DN/pixel/read. The scales include an arbitrary constant offset. The light blue points are data and residuals from regions excluded from the fit because of increased likelihood of scene dependent bias due to stars with pixel values >5000 DN/read within 400 columns of the trailing black in the excluded rows. The density of stars is higher in channel 20.2 in Q1 so the likelihood of stars very close to the trailing black is higher, leading to the evident higher number of obvious outliers in the excluded region in that channel.



Handling Black-Level Model Coefficients over Multiple Cadences

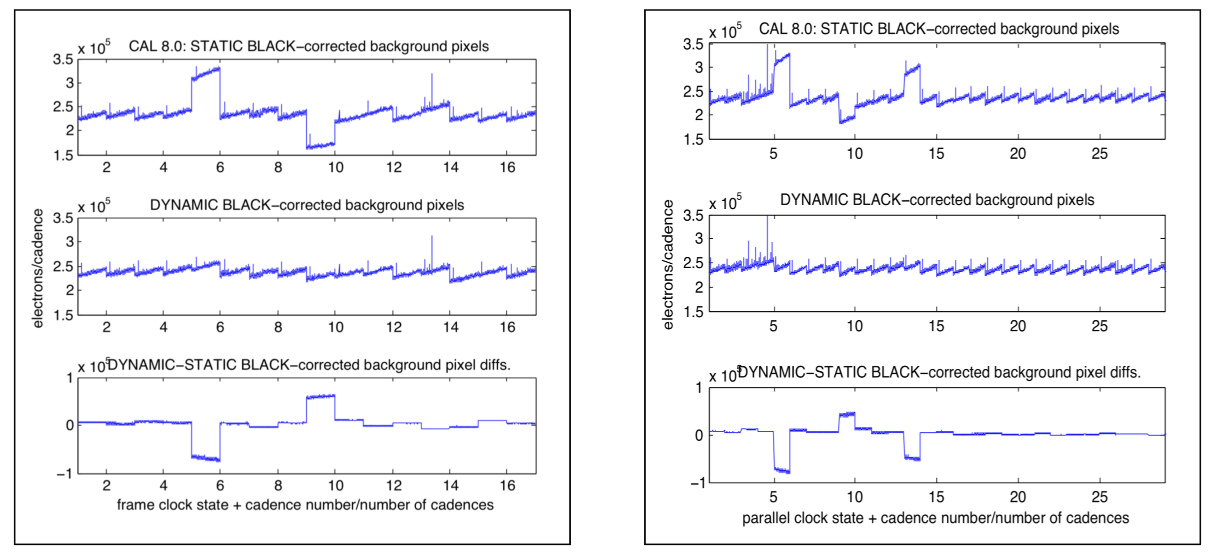
Spatial fit coefficients vs. time for channels 2.1 and 20.2 are shown. An adaptive fitting algorithm models coefficients as either discrete, constant, time and/or temperature dependent or smoothed.



Effect of Dynablack on Calibrated Pixel Time Series

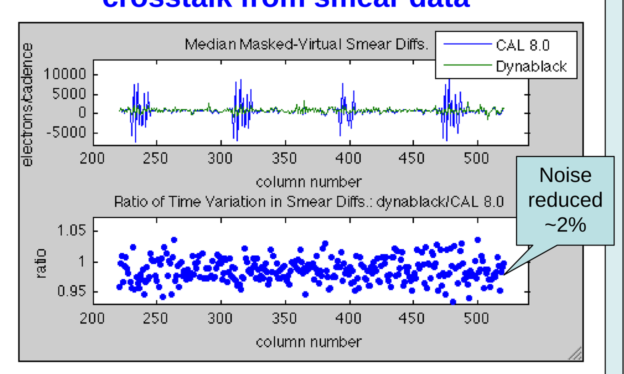
Derived black-level corrections are applied to smear collateral data in CAL and both black and smear corrections are applied to target and background pixels. The plots below compare differences between masked and virtual smear pixels and FGS crosstalk-affected background pixel time series both with and without Dynablack correction. Note 20 ppm for a 12th magnitude star is 600 electrons/cadence.

Frame FGS crosstalk-affected background pixels are corrected by Dynablack | **Parallel FGS crosstalk-affected background pixels are corrected by Dynablack**



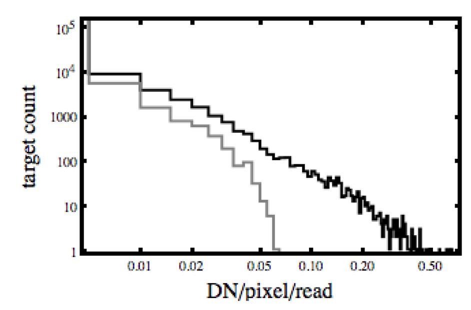
We can predict the effect on each target from the distribution of FGS clock states in the optimal apertures. Below is a histogram of peak-to-peak dynamic 2D black corrections per science target for all channels during Q1. The contribution of smear effects is shown in gray. Approximately 4% of targets are affected by > 0.02 DN/pixel/read (the level to affect a Kp =12 star by 20 PPM). [3]

Dynablack correctly removes FGS crosstalk from smear data



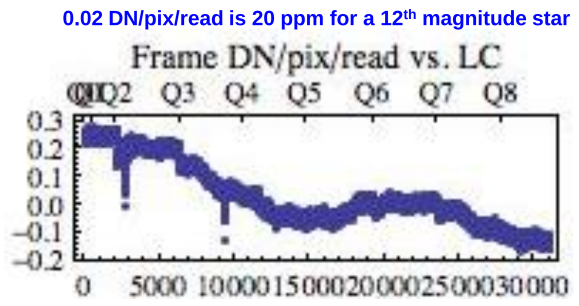
Histogram of Dynamic 2D Black Corrections

Q1 data over all science targets



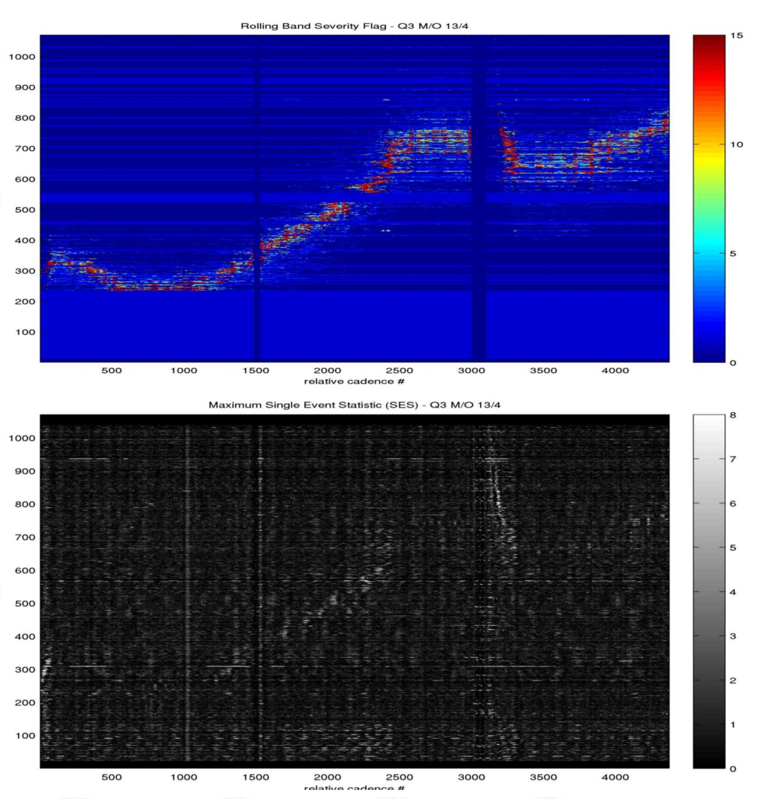
FGS Crosstalk Trend over Cadences

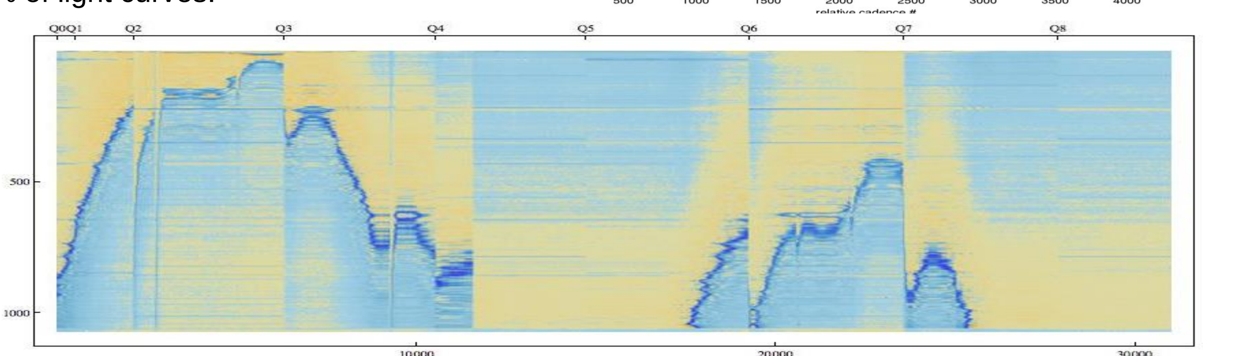
0.02 DN/pix/read is 20 ppm for a 12th magnitude star



Flagging Intervals of Excessive Black-Level Variation Due to Rolling Bands

Rolling band flagging results from channels 13.4 for Q3 show a strong rolling band for the entire quarter. The 4-bit severity code indicates regions of increasing rolling band severity. The maximum transit search single event statistic figure indicates that the rolling bands are often interpreted by the pipeline as having enhanced transit probability. Flagging rolling bands will potentially reduce false positive transit detections. Below: Dark blue features indicate long term rolling band trends in channel 13.4, which recur annually. 49 of 84 sky groups contain rolling bands over ~50% of rows, which may affect > 30% of light curves.





References

[1] Jenkins, J.M., et al., "Overview of the *Kepler* Science Processing Pipeline," ApJL, 713 (2), L87-L91 (2010).

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[3] Kolodziejczak, J. J., et al., "Flagging and Correction of Pattern Noise in the Kepler Focal Plane Array," *Proc. SPIE*, 7742, 38 (2010).

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