Abstract

As each Kepler frame is read out, light from each star in a CCD collects in successive pixels as they fall for the next row to be read out. This accumulation is the same in the masked rows at the start of the readout and virtual rows at the end of the readout as it is in the science data. A range of these “smear” rows are added together for each long cadence and sent to the ground for calibration purposes. We will introduce and describe this smear collateral data, discuss and demonstrate its potential use for scientific studies exclusive of Kepler calibration.[1,2]

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Integration Time for Smear Pixels

Beyond their utility for calibration, smear data represent full field projections from each module output, containing signal from every star in the field, summed over rows. Since Kepler acquires cadence data from only 8% of science pixels in the target apertures, the only continuous information we have on what’s happening in the other 94% of the pixels is from the smear data (full frame images taken several times per quarter provide more complete spatial information). The table below summarizes integration time parameters, and is based on a serial pixel read rate of 3 MHz, 1455 read intervals per row for 1070 rows, and a 58.5 integration-to-readout ratio. The data values acquired are the sum of 12 rows each of masked and virtual smear pixels.

<table>
<thead>
<tr>
<th>Integration Period Per Frame</th>
<th>0.01956 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout Period Per Frame</td>
<td>0.01956 sec</td>
</tr>
<tr>
<td>Readout Period Per Row</td>
<td>0.004485 sec</td>
</tr>
<tr>
<td>Smear Pixel Integration Period Per Frame</td>
<td>0.49664 sec</td>
</tr>
<tr>
<td>Smear Pixel Integration Period Per Row</td>
<td>0.000485 sec</td>
</tr>
<tr>
<td>Number of Smear Pixels Collected</td>
<td>24</td>
</tr>
<tr>
<td>Smear Datam Diffuse Background Integration per Row (50%, observing efficiency)</td>
<td>5.64 x 10^15 sec</td>
</tr>
<tr>
<td>Smear Datam Poet Target Integration Time per Row (80%, observing efficiency)</td>
<td>53400 sec</td>
</tr>
</tbody>
</table>

Smear. For calibration, all virtual rows at the end of the Science Pixels illuminate real pixels and pixels fall on the Kepler focal plane array while the pixels are clocked out during the readout period. This combined with the fact that there are 2 sets of 12 pixel sums, enabling a 24 pixel combined sum for what we are calling a smear datum, results in a total diffuse background integration time per datum which is longer than 1 year per year and approximately twice the 2.8 x 10^5 sec of background exposure received by the science pixels.

The light from a star falls on several pixels across rows and columns and its distribution depends on the sub-pixel centroid location and spatially varying PSF, however unless a star is near the edge of the science pixel region so that the PSF overlaps the edge, the exposure as defined by effective area x integration time is fixed by the readout period per row. If a star illuminates the telescope with a given flux in photons cm^-2 sec^-1, then the number of photons incident on the focal plane per year is this flux x effective area x the point target integration time listed below. The result is that the smear pixels are accumulating more than 50 sec/year on each of the 13 x 10^6 stars in the Kepler field.

But... Noise in Smear Pixels

Components of the variance of smear data are summarized in the table below along with signal-to-noise ratio for stars of several Kp values. Plots show the photometric precision on 1 long-cadence time scales as a function of Kp for the smear data in comparison to science pixels assuming typical aperture sizes for the science pixels and the ratio of smear data SNR to science data SNR. For bright stars, shot noise dominates and the ratio is the square root of the ratio of integration times, sqrt(1/157) = 1/53. However for Kp ~ 10, read noise begins to dominate and the photometric precision cuts off sharply. Thus the utility of the smear data for monitoring short term variation in most stars is limited.

<table>
<thead>
<tr>
<th>Kp</th>
<th>Signal</th>
<th>Bright Noise</th>
<th>Dark Current</th>
<th>Atom Gain</th>
<th>Read Noise</th>
<th>Photometric precision per long cadence for smear [Kp, SNR]</th>
<th>Signal for science targets</th>
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<tbody>
<tr>
<td>5</td>
<td>2.5 x 10^11</td>
<td>1.6 x 10^10</td>
<td>1.1 x 10^10</td>
<td>6.5 x 10^10</td>
<td>1.0</td>
<td>9.0</td>
<td>9000</td>
<td>1400</td>
</tr>
<tr>
<td>6</td>
<td>6.0 x 10^11</td>
<td>2.0 x 10^10</td>
<td>2.0 x 10^10</td>
<td>6.0 x 10^10</td>
<td>2.0</td>
<td>2.0</td>
<td>365</td>
<td>82</td>
</tr>
<tr>
<td>7</td>
<td>1.3 x 10^10</td>
<td>5.4 x 10^9</td>
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<td>5.4 x 10^9</td>
<td>5.4</td>
<td>5.4</td>
<td>54</td>
<td>21</td>
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The masked rows at the start of the readout contain only this smear plus dark current and the virtual rows at the end of the readout contain only the smear. For calibration, all of the columns of the smear data are collected for 12 masked rows and 12 virtual rows and are coadded over 270 frames for each long cadence. In the absence of a shutter, light continues to fall on the Kepler focal plane array while the pixels are clocked out during the readout interval. The charge collected in pixels during this time is called smear.

Charge accumulation in a single column due to illumination of a single pixel

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Unobserved Bright Stars on Science Pixels

A comparison of on-silicon stars in the KIC to the number observed sometime over Q1-Q9 indicates there are a significant number of very bright stars that have never been observed by Kepler. There are 323 such stars with Kp>10.

<table>
<thead>
<tr>
<th>Kp</th>
<th>In KIC on 5</th>
<th># Observed</th>
<th># Smear Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>66</td>
<td>37</td>
<td>29</td>
</tr>
<tr>
<td>8</td>
<td>145</td>
<td>101</td>
<td>44</td>
</tr>
<tr>
<td>9</td>
<td>609</td>
<td>130</td>
<td>70</td>
</tr>
<tr>
<td>10</td>
<td>245</td>
<td>134</td>
<td>103</td>
</tr>
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</table>

Summary

The raw smear data will be included in the set of archived Kepler data. Because of the unique continuously observing nature of the Kepler mission it is possible that, even with its limitations, the smear data could be mined for its scientific value. A list of benefits and limitations includes:

Benefits:
- Continuity of data.
- The only data available for some targets.
- Potential for adding to occasionally observed target data sets.
- Good background sensitivity may be useful for study of diffuse sources.
- More complete data from bright stars that saturate off the top or bottom of an image (using smear data from opposite end).

Limitations:
- Only raw data will be available, so calibration and other preparation steps are required.
- Projected columns may include multiple interesting stars, but data labels could be used to reduce confusion.

References