# Kepler photometric accuracy with degraded attitude control: Simulation of White Paper Attitude

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The present document describes the expected photometric accuracy which may be obtained from analysis of Kepler data in the case of degraded attitude accuracy – along the lines described in the Call for White Papers. The present document is an extension to DASC/KASOC/0043.

All simulations are based on the Photometry simulator developed by Ridder, Arentoft and Kjeldsen (2006, MNRAS, **365**, 595-605).

## The degraded attitude of Kepler

Based on information in the Call for White Papers we have specified a degraded attitude. The simulations of jitter and minor drift of Kepler are based on the description in section 3.7 in the Kepler Instrument Handbook (KSCI-19033, 15 July 2009, NASA Ames Research Center):
http://keplerscience.arc.nasa.gov/calibration/KSCI-19033-001.pdf.
The philosophy behind the simulated degraded attitude is first to create a simulation of the 3-axis stabilized jitter which follows the requirements shown in Figure 18 in the Kepler Instrument Handbook (see Figure 1 below).

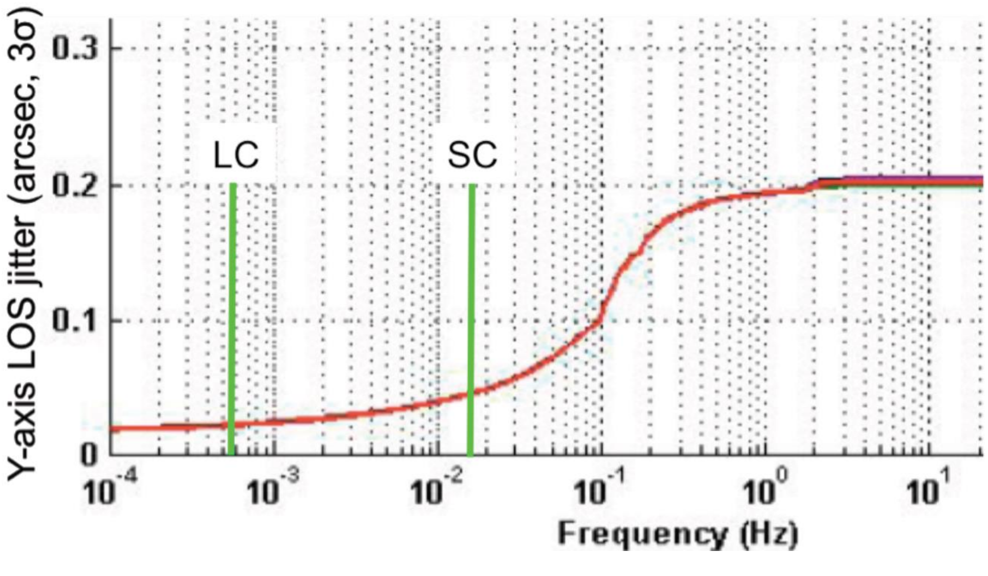


***Figure 1.*** *From Kepler Instrument Handbook (figure 18, pg. 40). The figure indicate the 3σ RMS single-axis attitude error (combined jitter and drift). Reaction wheel jitter above 20 Hz is not included and will mainly affect the PSF.*

The high frequency attitude noise is a result of spacecraft motion that can't be removed by use of the guiding sensors and can therefore not be corrected by use of the reaction wheels. At low frequencies the main noise is drift and this is corrected almost entirely by the reaction wheels. In the simulations we therefore keep the high frequency noise component unchanged but increase the low frequency to simulate the degraded performance of the Kepler attitude (the attitude in pitch (X-coordinate) and yaw (Y-coordinate) is drifting around with a scatter of 0.5 arcsec).

On top of that we define a drift of 0.9 arcsec/min as show in the Call for White Papers and shown below in figure 2.

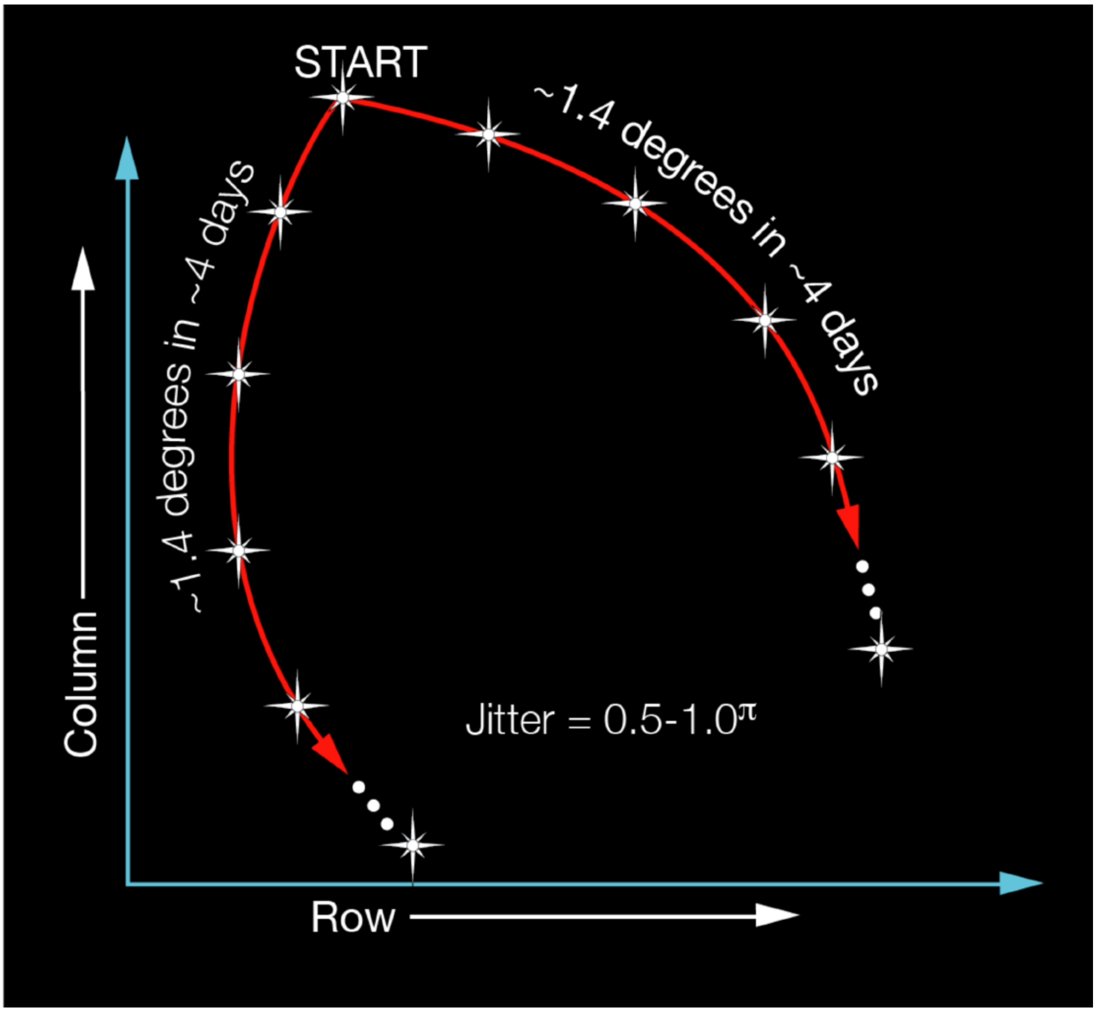


***Figure 2.*** *Schematic view of two possible point-drift mode observations on a CCD (see White Paper call for details)*

## The CCD sensitivity

An important part of the simulation is the CCD sensitivity variation. There are three major components that are used to describe the relevant sensitivity variability. References are made to the Kepler Instrument handbook: http://keplerscience.arc.nasa.gov/calibration/KSCI-19033-001.pdf (KSCI-19033-001, 15 July 2009):

1. **Global pixel-to-pixel (inter-pixel) variations**. In the present simulation we use about 5% sensitivity variability peak-to-peak of a 30x30 pixel area. According to the Kepler Instrument Handbook table 9 one can expect a 1% standard deviation in the Photoresponse non-uniformity for the Kepler chips which is in agreement with a 5% peak-to-peak sensitivity variation. We assume that 80% of the global pixel-to-pixel variation can be removed via flat fielding (as discussed in the section 4.14 in the Kepler Instrument Handbook).

2. **Intra-pixel random variations**. In the present simulation we use 25% peak-to-peak variability within a pixel (on a scale corresponding to 1% of the pixel area).

3. **Sensitivity drop due to pixel-channel (intra-pixel drop due to the gate structure of the CCD chip)**. In the present simulation we use 10% drop along 10% of the pixel in both the X- and Y-direction.

The corresponding sensitivity variability is shown in figure 3 below.

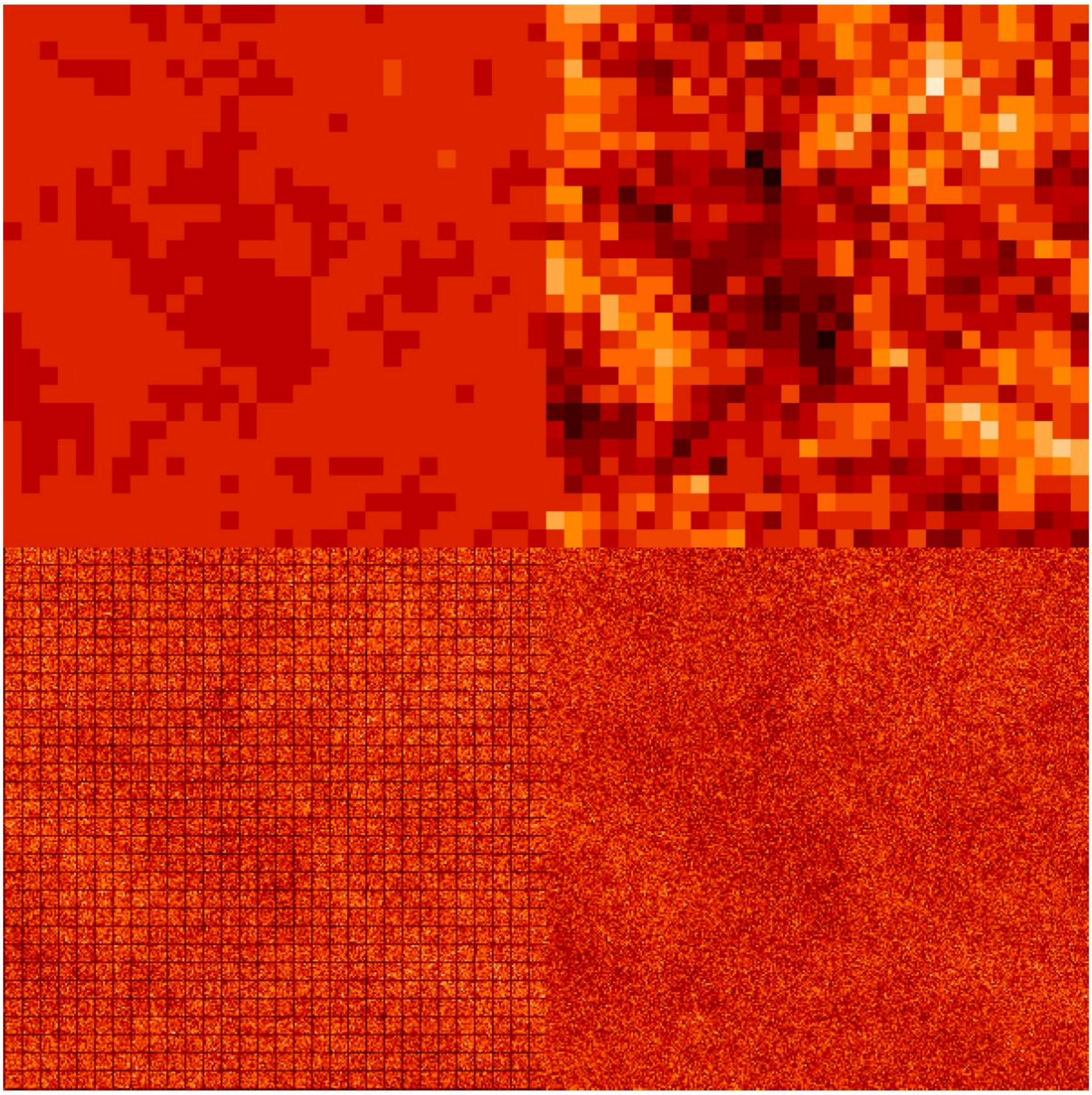

***Figure 3.*** *The lower left corner show the combined detector sensitivity variation in the present simulation including global variations as well as intra-pixel and pixel-channel sensitivity drop. The upper left corner show the global sensitivity variations at the same scale as used in the lower left corner. The upper right corner shows the global pixel-to-pixel variability using a finer scale. The lower right show the sensitivity variability without the pixel-channel sensitivity drop.*

## Simulating the photometric performance

Using the simulated attitude as well as the simulated sensitivity variability we finally use a stellar PSF (simulating the Kepler PSF) and create images which are then analysed. In figure 4 we show an example of a 30x30 pixel image and in figure 6 we show the extracted photometric variability for the simulated time series. The photometric analysis is done using three different apertures (defined in the software) and we also measure the position of the PSF on the CCD which can then be compared to the attitude input.

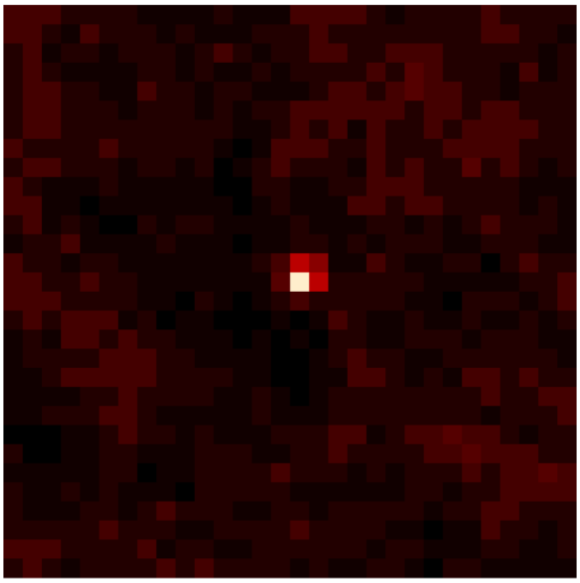

***Figure 4.*** *A single simulated CCD-frame showing a single star in the chip.*

***Figure 5 (below).*** *Figure 15 from the Kepler Instrument handbook (KSCI-19033) showing the PSF (or PRF) for a point source in the focal plane (detected by use of Kepler).*

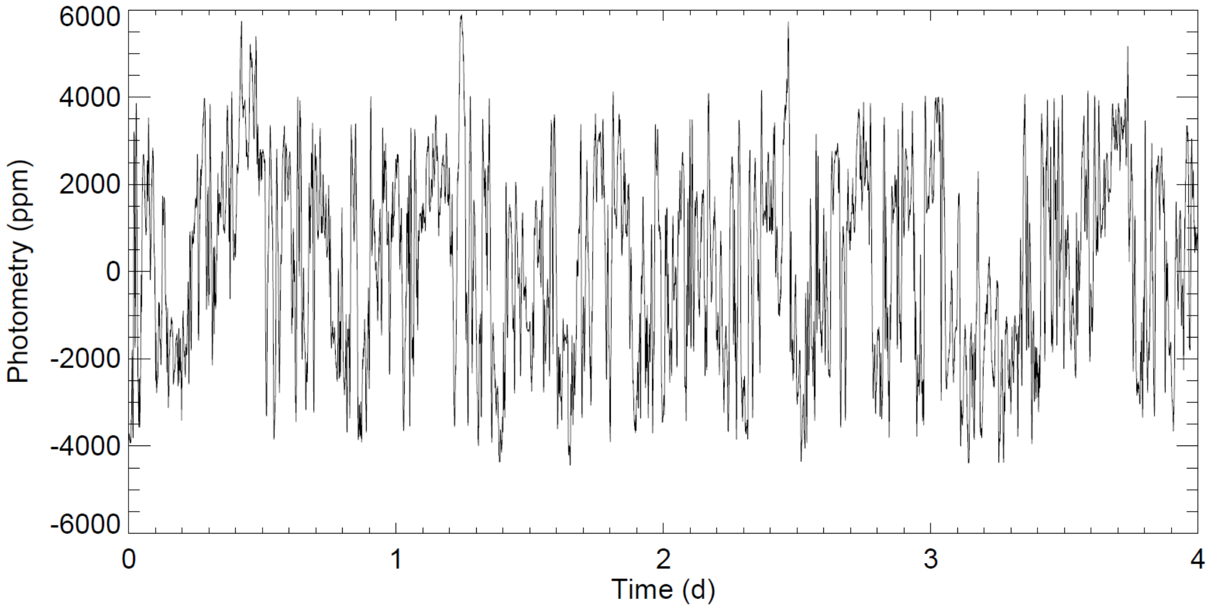


***Figure 6.*** *Extracted raw photometric variations using the attitude variations as described above. No photon noise is included in this time series and no intrinsic stellar variability is included.*

### The noise in the power spectrum

Based on the simulations we can then calculate the noise level in the power spectrum. This noise should be compared with the stellar signal.

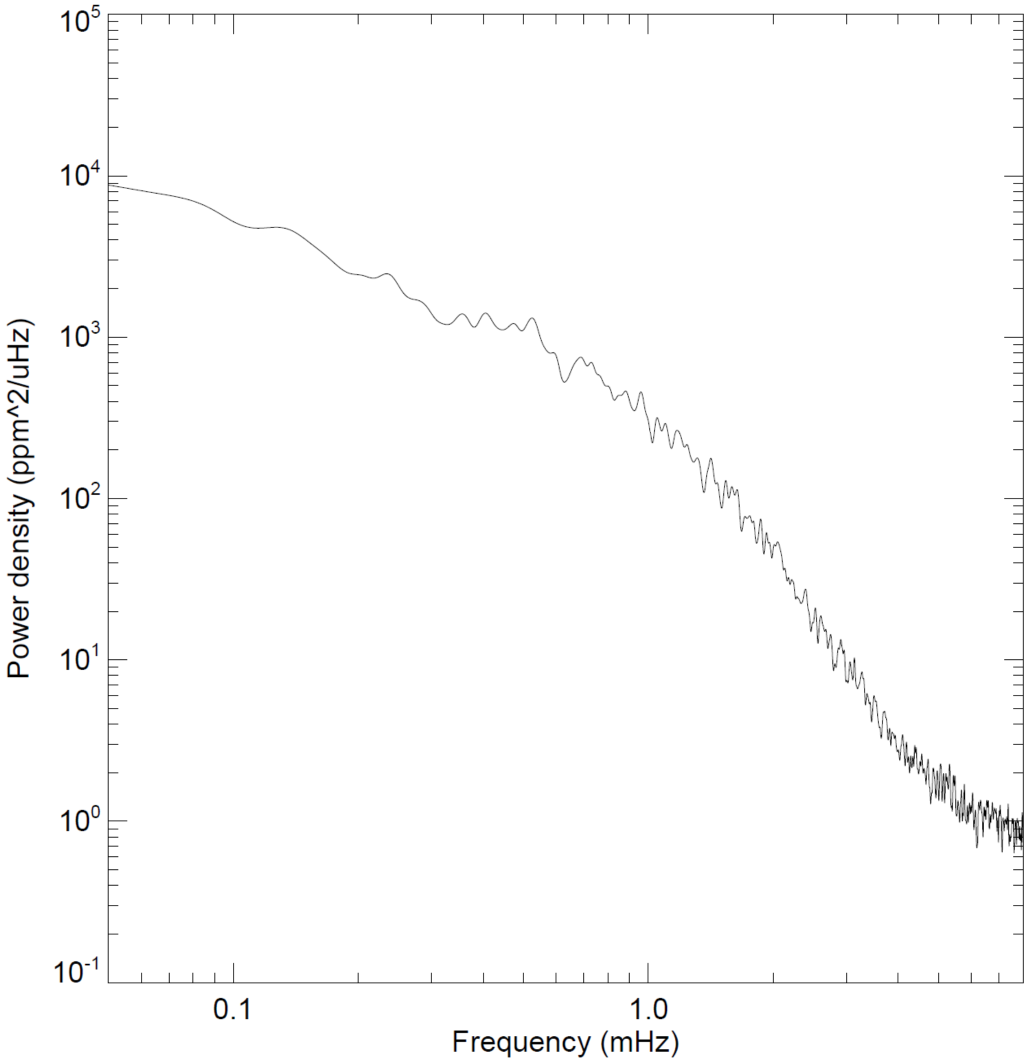


***Figure 7.*** *Power density spectrum for the simulated time series. The power density follow a non-white spectrum with high noise a low frequency. The power level should be compared to the stellar signal and stellar background noise for e.g. solar-like stars.*