Gaia: Cleaning the Data

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Electronic Bias and Background Light from Space

The focal plane on the Gaia Space Telescope is composed from charge-coupled devices (CCDs) similar to the ones in the camera in your mobile phone, but larger and with greater sensitivity and resolution. They are arranged on the focal plane as shown in Figure 1.
At Edinburgh, we are deeply involved in cleaning up and calibrating the data captured by these CCDs. This poster talks about two of the problems we address. The first, caused by stray light, originates outside the telescope. The second, caused by electronic pattern noise in the CCD array itself, comes from inside the Gaia instrument.
In both cases the telescope runs special data capture sequences to obtain calibration data. These calibration sequences are then telemetered to the ground, where software programmes developed here at the Institute for Astronomy are used to create mathematical models of the stray light and electronic pattern noise. These models are then used to clean the data from stars and other celestial objects captured during routine scanning of the sky by Gaia.

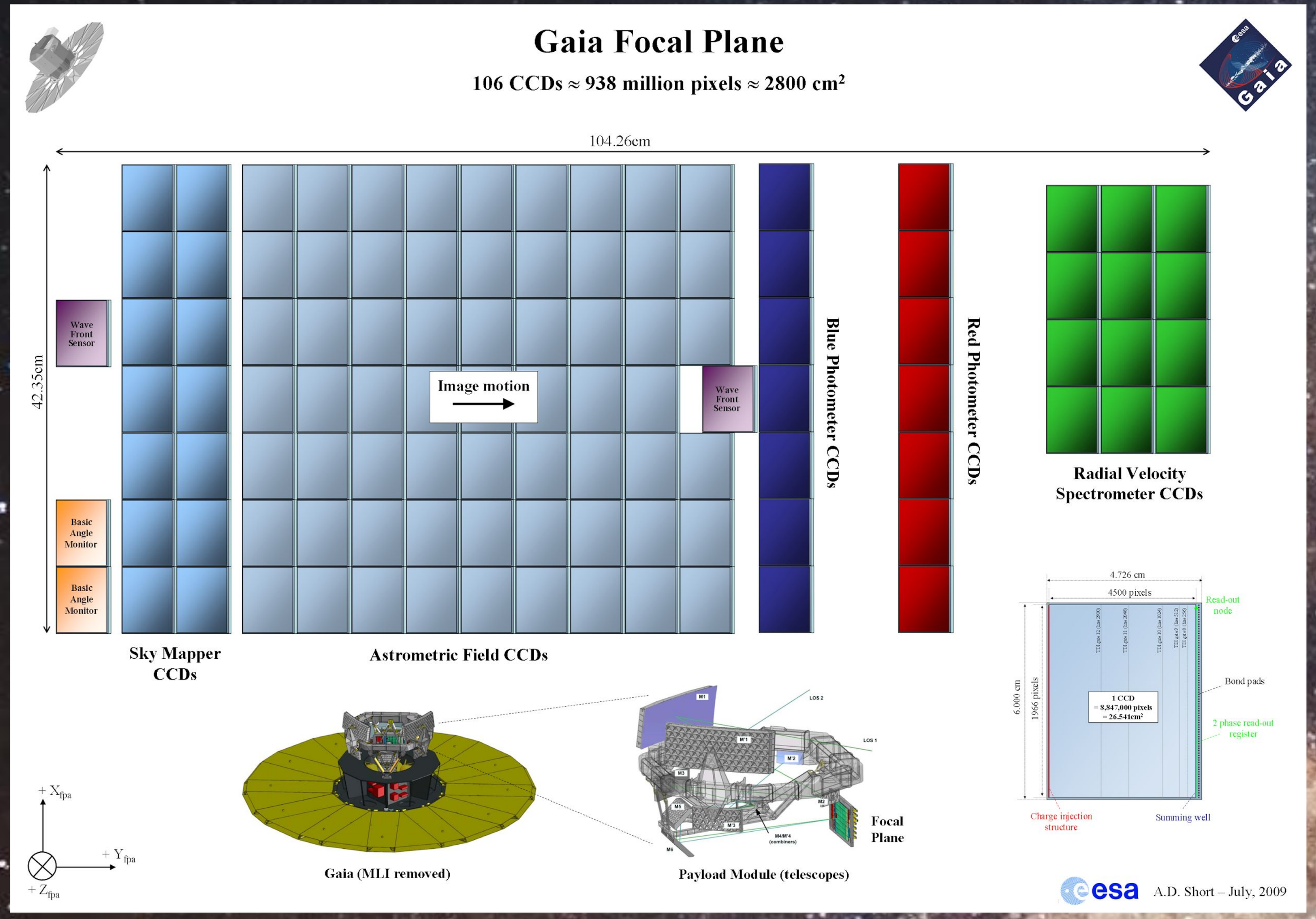

Figure 1: The Gaia focal plane. Each small square represents one large CCD. These are arranged to detect stars (Sky Mapper), and measure their position and brightness (Astrometric Field), colour (Blue and Red Photometric CCDs) and radial velocity (RV Spectrometer CCDs). Picture credit: ESA / Airbus DS / Alex Short.

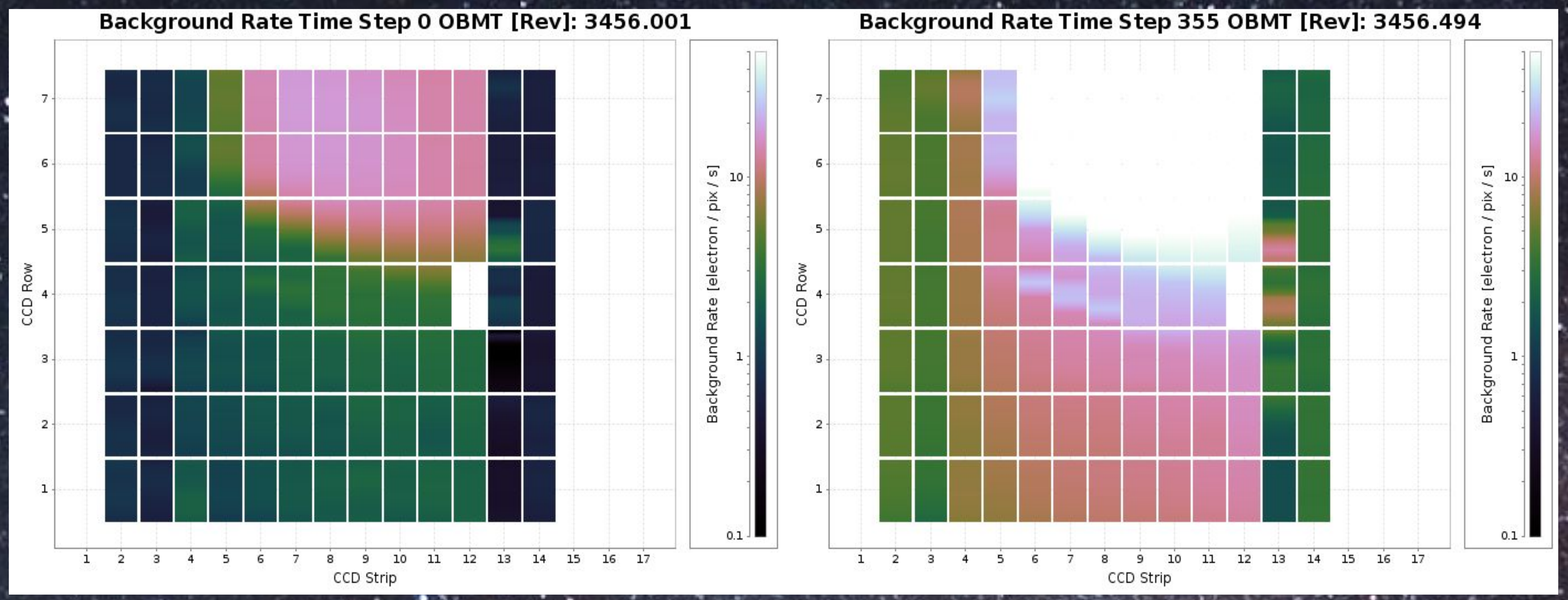

Figure 2: Examples of the stray light (AstroPhysical Background) model, showing the minimal (left panel) and maximal (right panel) extent of the stray light as it varies during a single revolution of the telescope during the Galactic Plane scan.

Stray Light (Astrophysical Background)

To increase the sensitivity of Gaia, the instrument is protected from the sun by a large sun shield (see bottom of Figure 1). This acts by blocking background light and keeping the instrument at a low temperature of 160K where it is more sensitive. However, some features of the design of the telescope allow some stray light to get past. Its lightweight and compact design for launch into space (see also bottom of Figure 1) meant it could not have heavy and cumbersome black baffling to absorb stray light. It was also not possible to tape the ends of the sunshield in case it stuck when it opened. Unfortunately this meant some of the tiny fibres from which the sunshield is made scatter light back into the telescope.
To estimate the Astrophysical Background, Gaia continuously takes measurements from the edges of faint stars and from special calibration areas of empty sky. These are then used to calculate what the background light level is at points across the sky over time as the telescope scans. Our calibration programmes use this data to create a mathematical model of the background light across the entire focal plane at each point in time. See Figure 2 for some examples of this model.
Our models show the stray light has a wide dynamic range, varying by a factor of 100 times from its dimmest to brightest. When used in the daily processing pipeline for new data coming from the telescope, these models are effective in removing the background light level from samples within required tolerances. At a later stage, all of the data from Gaia will be reprocessed to create the final 3D map of the galaxy, and for this work we are investigating new ways of modelling the stray light with ever increasing accuracy.

Electronic Pattern Noise (Bias Non-Uniformity)

As Gaia rotates, each line of pixel data is read from a readout line (or serial register) on the right hand side of each CCD. The diagram in the bottom right of Figure 1 shows this detail. The readout is complicated by a number of factors. The voltage on each CCD is kept above zero so that noise in the readings cannot produce negative numbers. This is the electronic bias. This bias varies (common baseline non-uniformity) and is also disturbed as charge is moved into the readout register ("glitching") and as empty areas of sky are read quickly ("flushing"). These effects together are called Bias Non-Uniformity.
About every 4 months, Gaia runs a special set of calibration sequences to measure the bias non-uniformity. Electronic gates block signals from reaching the readout register. This is like closing the shutter on a camera. Then special samples measure the electronic offsets when no signal from incident light is present. Our calibration programmes use this data to model the bias level, and fluctuations in it, caused by common baseline variation and the glitch and flush anomalies.
The top panel of Figure 3 shows how the Bias Non-Uniformity disturbs the zero level in the electronic signal. In particular this data shows a high common baseline level of about 20 electrons, a strong glitch feature which causes the large jumps in the zero-point level and bumps and gradients in the signal values. In sample data corrected with our mathematical models (lower panel) the common baseline is reduced to around 5 electrons, the glitch is almost eliminated and pattern noise levels are significantly flattened.

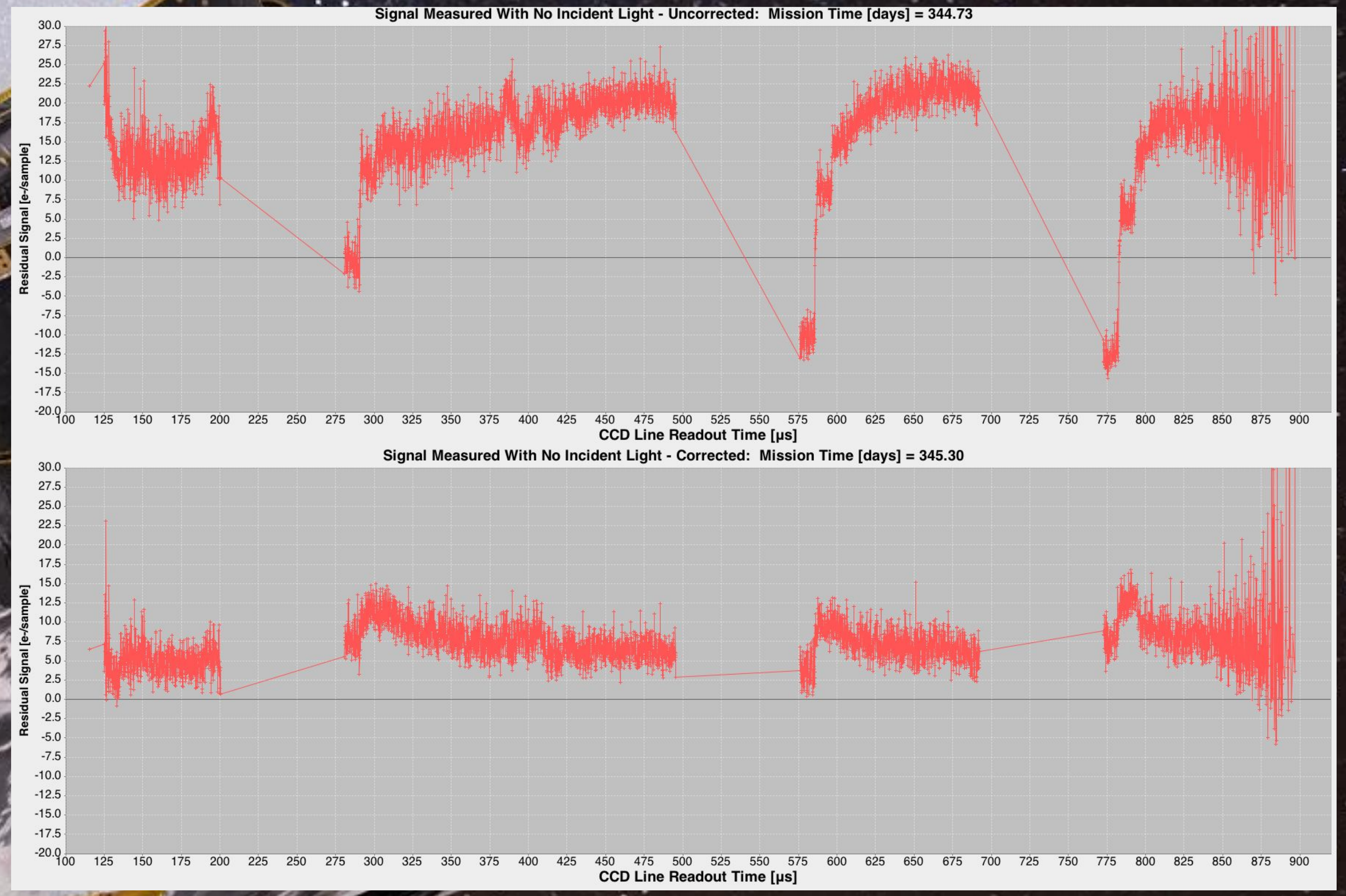

Figure 3: Example of cleaning up data to reduce effects of electronic noise (Bias Non-Uniformity). When there is no incident light, corrected electronic signal should be zero (black line). In fact, we see the effect of Bias Non-Uniformity as lines of data are read from the CCD (upper panel). These effects are greatly reduced by the application of our mathematical models to the data (lower panel).

Gaia: The Movies

The two movie clips associated with this poster show how the electronic bias and stray light features vary over time in different ways. In both cases, the plots shown on this poster were captured from the movie clips.

The Stray Light (Astrophysical Background) movie shows how the model of background light evolves as the satellite completes a single revolution (6 hours) while scanning along the brightest part of the sky in line with the Milky Way (Galactic Plane scan).

The Electronic Pattern Noise (Bias Non-Uniformity) movie shows how the average bias signal measured across the readout of each line of pixels varies very slowly over 700 revolutions of the satellite (approximately 6 months).

Gaia Artist's impression - credits: ESA/ATG medialab; background image: ESO/S. Brunier