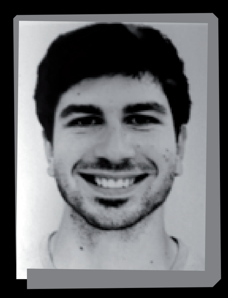
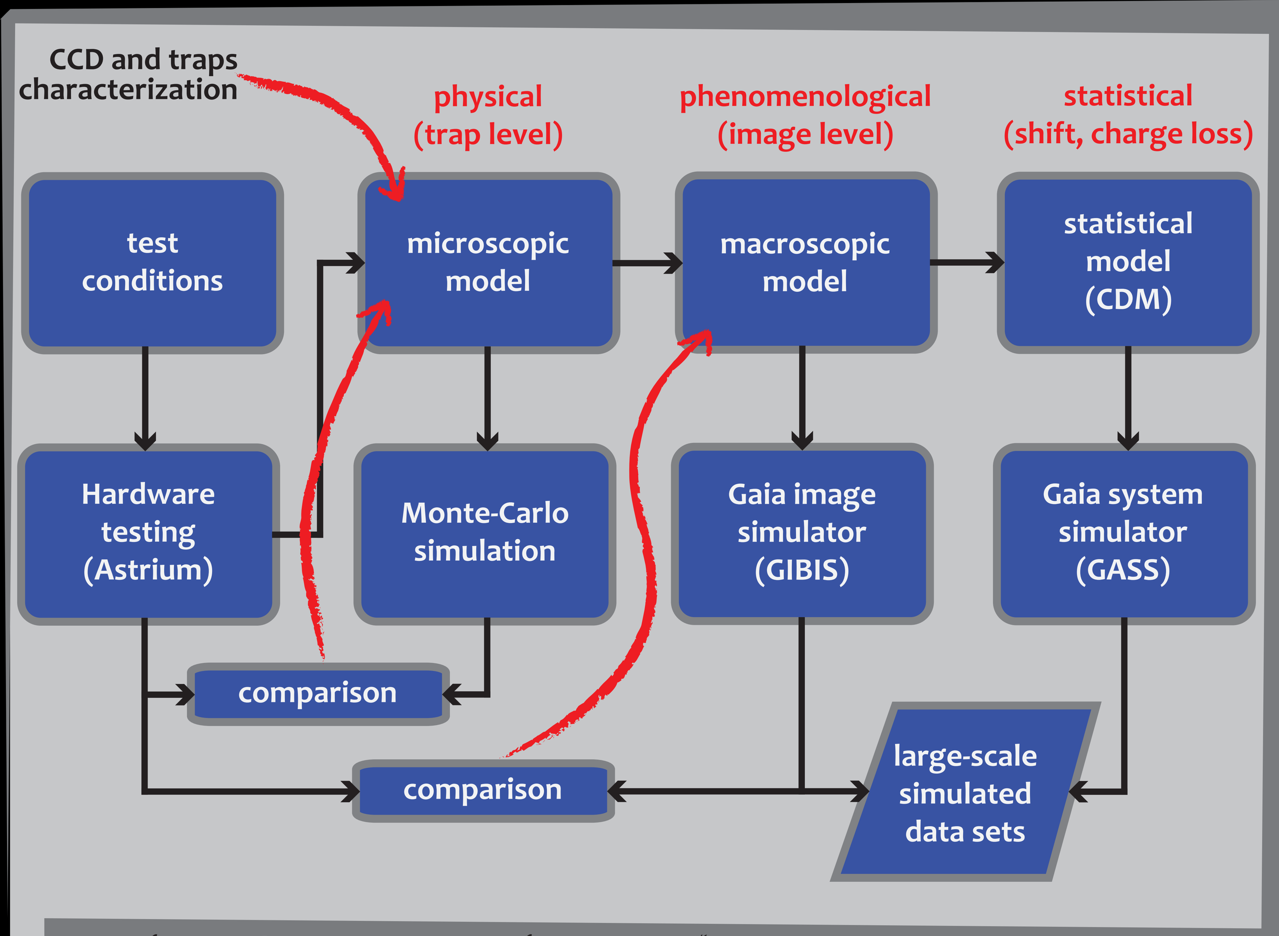


Radiation Damage Effects on Gaia CCDs
Modelling to Mitigate the Threat

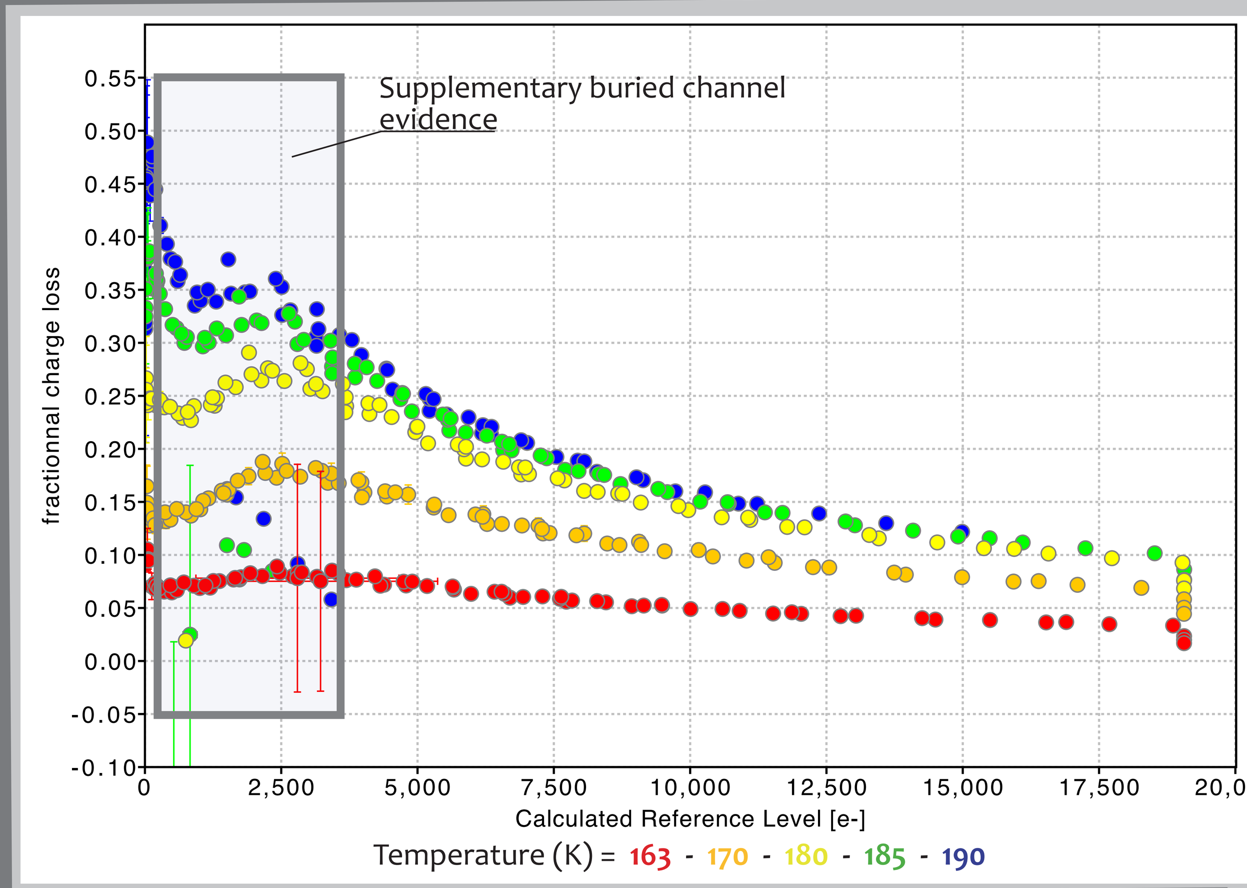
Thibaut Prod'homme



*DPAC CTI Mitigation Approach**

Gaia aims to create the most complete and accurate stereoscopic map of the Milky Way by collecting positions, proper motions, radial velocities, and astrophysical parameters for one billion stars. The main goal is to revolutionize our understanding of the formation and evolution of our galaxy, but Gaia will strongly affect every astronomical discipline. The required astrometric accuracy is extreme, e.g. the end of mission parallax error is required to be 12-25 micro-arcseconds for a 15th magnitude star. The corresponding requirement on the residual image location error per CCD transit is ~0.01 pixels (~0.6 mas).

Solar protons emitted during flares will continuously damage the CCDs during the 5-year mission lifetime. For all measurements of Gaia this will lead to large charge loss and signal distortion, which will cause a decrease in their precision. The only way to mitigate these effects and reach the required scientific performance is to develop a detailed understanding of radiation damage effects through a combination of experimental results and physical modelling.



RC2 Analysis: Fractionnal Charge Loss in Charge Injections

Modelling Efforts

CCD CTI (Charge Transfer Inefficiency) modelling is required to get a better and full understanding of the radiation damage future impact on Gaia data as well as to recover Gaia's scientific performance. The Gaia DPAC (Data Processing and Analysis Consortium) plans to mitigate CTI effects include forward modelling using a fast analytical model. Thus the Gaia community is interested in every level of CTI modelling. Electron density distribution modelling and pixel level physical Monte-Carlo simulations are mandatory to anticipate CTI effects as close as possible to the physical reality and to help the development of top-level models. While the instrument simulator and the data processing itself require fast phenomenological and statistical models.

My involvement in this global effort takes place at each of those levels with the development of CEMGA (CTI Effects Models for Gaia), a platform to host the above models. It provides a detailed description of physical entities such as CCDs, pixels or traps, and methods to interact with them. CEMGA offers a rigorous environment for testing and validating implemented models as well as comparing them. It comes with a set of preconfigured simulated experiments such as First Pixel Response and various tools to analyse the results and compare them to experimental data.

Experimental Study

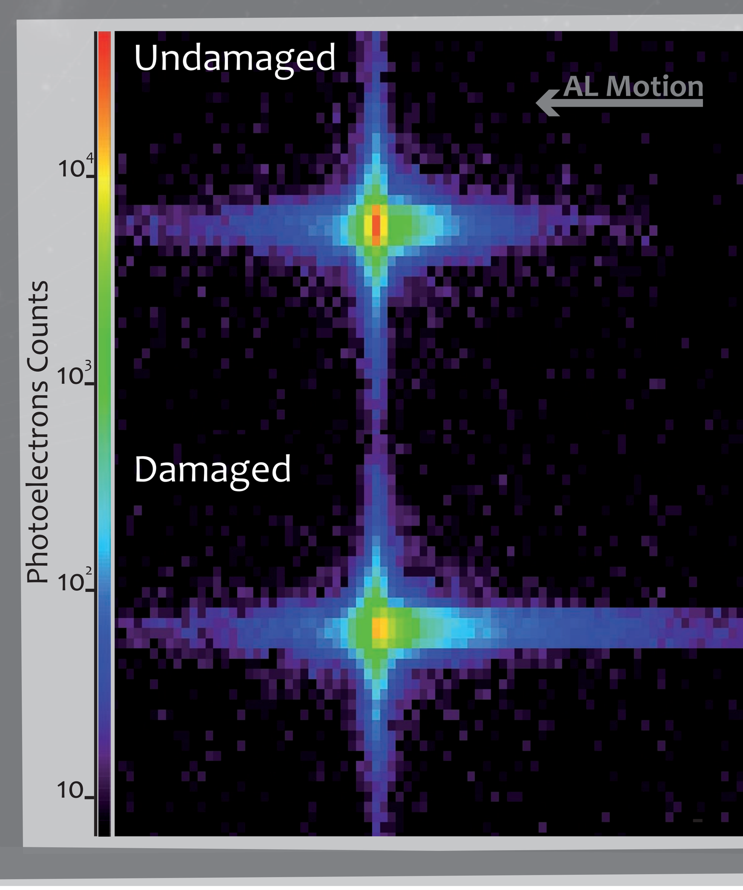
Gaia's manufacturer, EADS Astrium, is carrying out tests on irradiated CCDs to evaluate the potential threat of radiation damage for the mission accuracy requirements. Testing Gaia CCDs in realistic conditions is a true technical challenge; the tested CCD has to be operated in Time Delay Integration mode at low temperature (T = 163 K) with the lowest optical background possible. Furthermore the characterization bench has to simulate the three different instruments of Gaia (astrometric field, photometer and spectrometer). So far three different test campaigns have been realized. In order to help the modelling effort and in particular with the ambitious aim to constrain the relevant physical parameters, Scott Brown (IoA Cambridge) and I re-analyzed Astrium radiation campaign 2. In this re-analysis we used the first pixel response method to derive the trap density and to characterize the full well capacity of the supplementary buried channel. We also found that the number of detected traps varied as function of the signal size and then deduced information about the behaviour of electron density distribution.

Research Main Goals

I.
Develop a deeper understanding of the physics of CTI. Current issues:
- Real shape of the electron density distribution in Gaia CCDs
- Trapping at very low signal levels

II.
Develop a detailed understanding of the illumination history dependence of CTI effects.

III.
Synthesize acquired knowledge to be used in calibration procedures for the Gaia data processing.

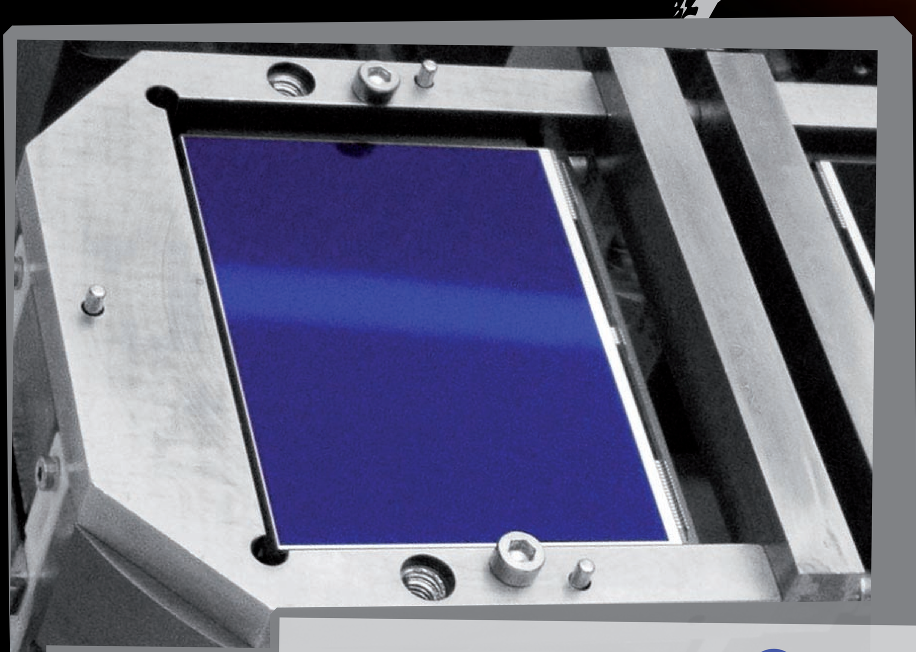


The picture on the left is the outcome of a physical pixel level Monte-Carlo model simulating unaffected and CTI affected transits of a V = 14 magnitude star over a Gaia CCD. The damaged has been increased to clearly bring out the photo-centre shift.

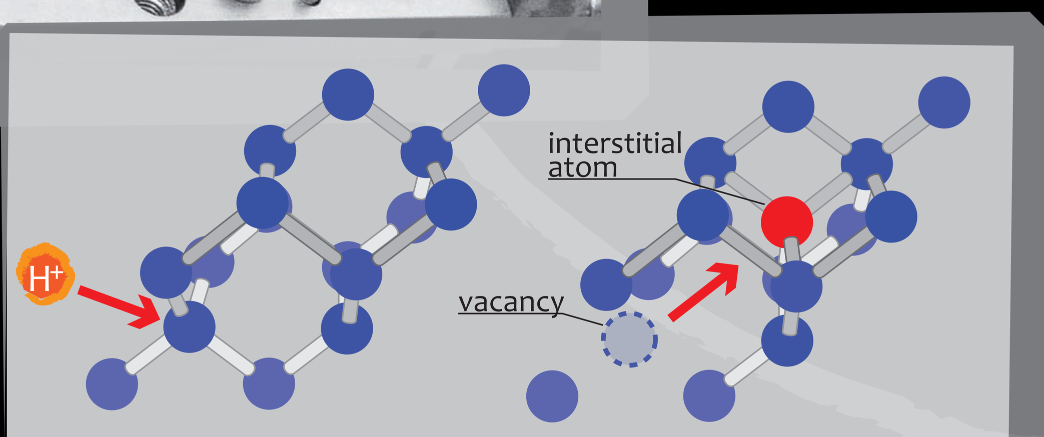
The bottom picture is the result of a similar experiment with a realistic amount of 3 traps per pixel. After the binning of this extended Gaia telemetry window (12 x 21 pixels) CTI effects can be clearly seen. The charge profile is distorted; electrons are trapped in the leading edge and released later to form a charge tail. The centroid bias is 8.6 mas and the relative charge loss 11.5 %.

CTI in a Nutshell

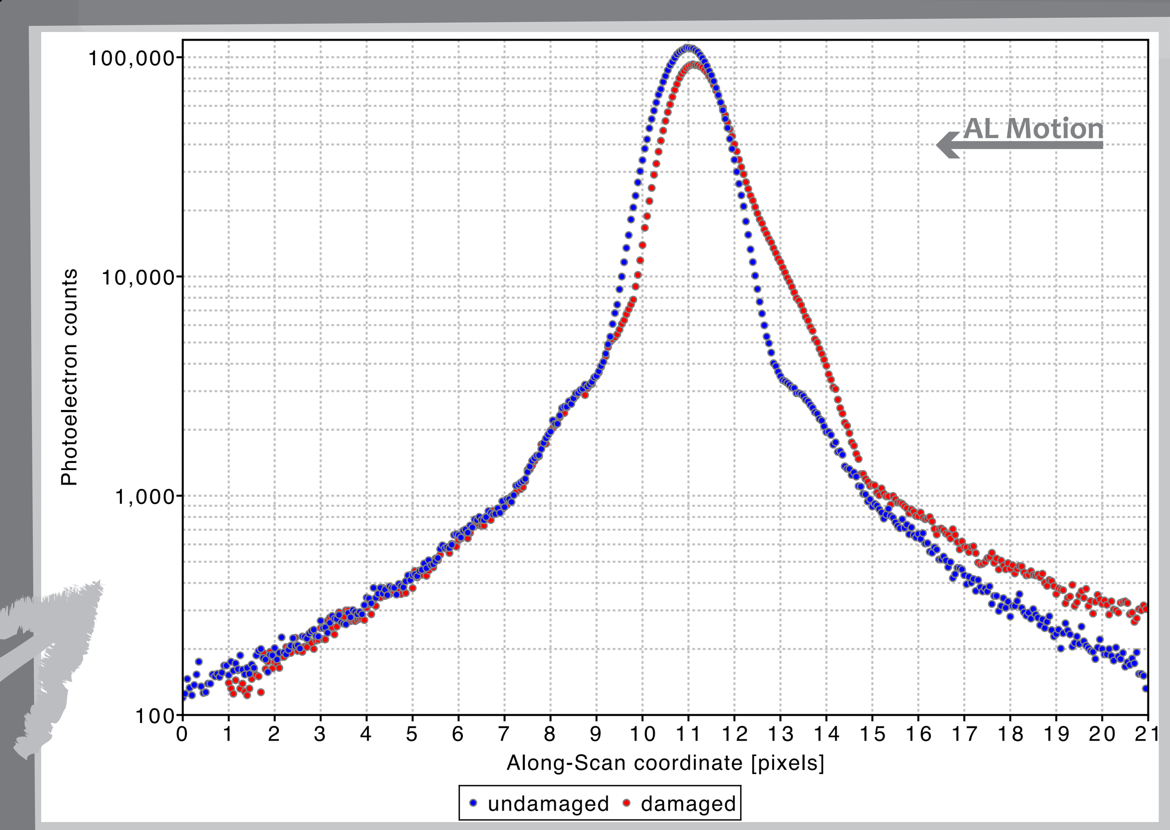
When colliding with Gaia's focal plane, energetic protons from solar flares will displace CCD silicon atoms. These displacements create interstitial atom - vacancy pairs. This changes the electrical property of the semiconductor by creating undesired energy levels in the forbidden gap, which trap electrons from the valence band and release them after a while. Radiation induced vacancies can gather in clusters, diffuse in the lattice and recombine with impurities such as phosphorous or oxygen atoms. This phenomenon gives birth to different trap species with different energy levels, capture cross sections and time-release constants. The traps cause a drastic increase in the CCD charge transfer inefficiency.



Gaia CCD



Displacement damage in Si lattice



Monte-Carlo pixel level simulations

* Schematic courtesy of Prof. L. Lindegren (Lund).
Sun image courtesy of SOHO/[instrument] consortium (ESA & NASA).
Milky Way Panorama courtesy of Lund Observatory.
Gaia spacecraft model courtesy of EADS Astrium.
Gaia CCD photograph courtesy of e2v technologies.

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