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# Development of a hybrid algorithm for time-resolved stellar photometry from space images

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## Abstract

The CoRoT satellite, inserted in a low Earth polar orbit, at 896 km of altitude, is exposed to a radioactive environment that may affect the instrumental components. Effects of charged particle impacts on the on-board electronics and optics have been minimized by the use of radiation-hard components and proper data reduction techniques. However, when the satellite crosses the South Atlantic Anomaly, the CCDs are exposed to strong radiation, subjecting up to 9% of the whole satellite's imaging duty cycle to some kind of impact damage.

This work presents an innovative hybrid photometry algorithm that takes advantage of a high-resolution instrumental point spread function (PSF) and of the high signal-to-noise-ratio (SNR) obtained in the on-board aperture photometry, to extract a more accurate photometric signal from the observed stars. It takes into account the total standard deviation in each pixel, formed by Poissonian and readout noises. Preliminary studies indicate this methodology may achieve important gains in photometric precision and increase the duty cycle up to 97%, enabling robust and accurate data exploitation.

## Background

### Time-Resolved Stellar Photometry

An overview of the literature displays three main techniques to perform time-resolved stellar photometry from space CCD images: aperture photometry, PSF-fitting photometry and threshold photometry.

Aperture photometry defines a mask which represents the CCD pixels to be summed up in the computation of the collected photon flux for a given star. This method presents very high precision for isolated, bright stars and for stable satellite attitude (low jitter scenarios). It is the data reduction technique implemented on-board, due both to link capacity constraints (given the large number of targets simultaneously observed by the instrument) and to its deterministic algorithm. Fitting photometry allows restoration of degraded stellar images through deconvolution processes, using the point spread function (PSF) of the instrument itself. This technique presents better performance for crowded fields and for faint stars; it also presents robustness in the presence of disturbances such as stray light or high satellite attitude jitter. Finally, threshold photometry takes into account only those pixels whose values are above a given pre-computed level. This method is used only in scenarios with excessive satellite depointing due to attitude jitter, or in cases where the instrumental PSF is poorly known. Therefore, it is not used in the CoRoT mission.

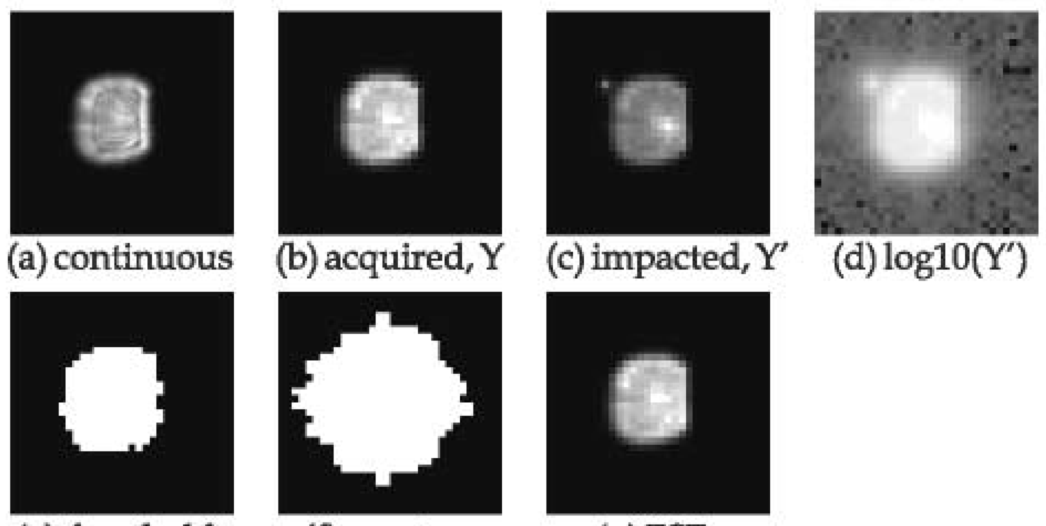


Figure 1: sequence of simulated acquired images by CoRoT, and commonly used photometry techniques.

### The South Atlantic Anomaly

The South Atlantic Anomaly (SAA) is the region where the inner Van Allen radiation belt (a torus of energetic charged particles around Earth) makes its closest approach to the planet's surface. Satellites and other spacecraft passing through this region of space actually enter the Van Allen radiation belt and are bombarded by protons that may exceed energies of 100 MeV at a rate of 3000 'hits' per square centimeter per second. This can produce 'glitches' in astronomical data, problems with the operation of on-board electronic systems, and premature aging of computer, detector and other spacecraft components.

The effects of the interaction between energetic particles and the lenses are almost limited to fluorescence, leading to a very small contribution to the mean background level. The effects on the electronics are somewhat minimized by the use of radiation-hard components. The effects of charged particle impacts on CCDs, however, may interfere in the photometric curves in two different ways: transient artifacts on the acquired images, created by eventual e-h pair, and permanent damage due to non-ionizing interactions. The focal plane is shielded with 10 mm of aluminum, which is enough to stop almost the whole population of trapped electrons, and protons below 50 MeV.

However, when crossing the SAA (8 to 10 passages per day), the CCDs are exposed to up to 10 minutes per passage of strong radiation, which reduces the whole satellite's duty cycle down to approximately 91%.

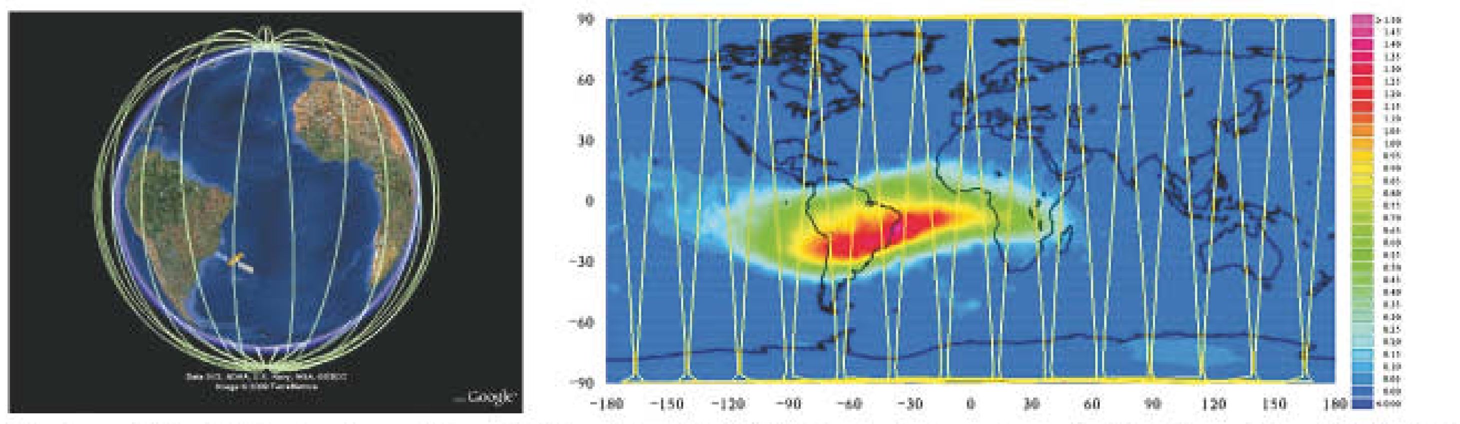

Figure 2: two illustrations showing a 24-hours CoRoT's trajectory, crossing 8 times the SAA in the period. (Left Image Source: TerraMetrics/Google Earth. Right Image Source: Cnes/CLS. Satellite Tracker Script: Robert Simpson, Cardiff University)

## Methodology

This work contributes to the efforts associated to the ground-based reduction of scientific data, and presents an innovative hybrid photometry algorithm that takes advantage of a high-resolution instrumental point spread function (PSF) and of the high signal-to-noise-ratio (SNR) obtained in the onboard aperture photometry, to extract a more accurate photometric signal from the observed stars. It takes into account the total standard deviation in each pixel, formed by Poissonian and readout noises.

Figure 3 illustrates the main idea behind the hybrid algorithm: the acquired CCD image (a) – in blue – provides a high SNR ratio near the centroid of the star, but its direct exploitation (via aperture photometry) is very sensitive to jitter and SAA effects, while its modeled PSF (b) – in red – presents better SNR far from the centroid and is robust to particle impacts. The algorithm evaluates the uncertainties associated to each of these sources and then selects the best compromise between both, switching between high SNR central pixels and low uncertainty edge pixels, thus eliminating impacted and/or high uncertainty pixels – in red, zoomed-in in (c) – in (a) and increasing the global SNR, to compose the final hybrid image (d) from which the light curve is later derived.

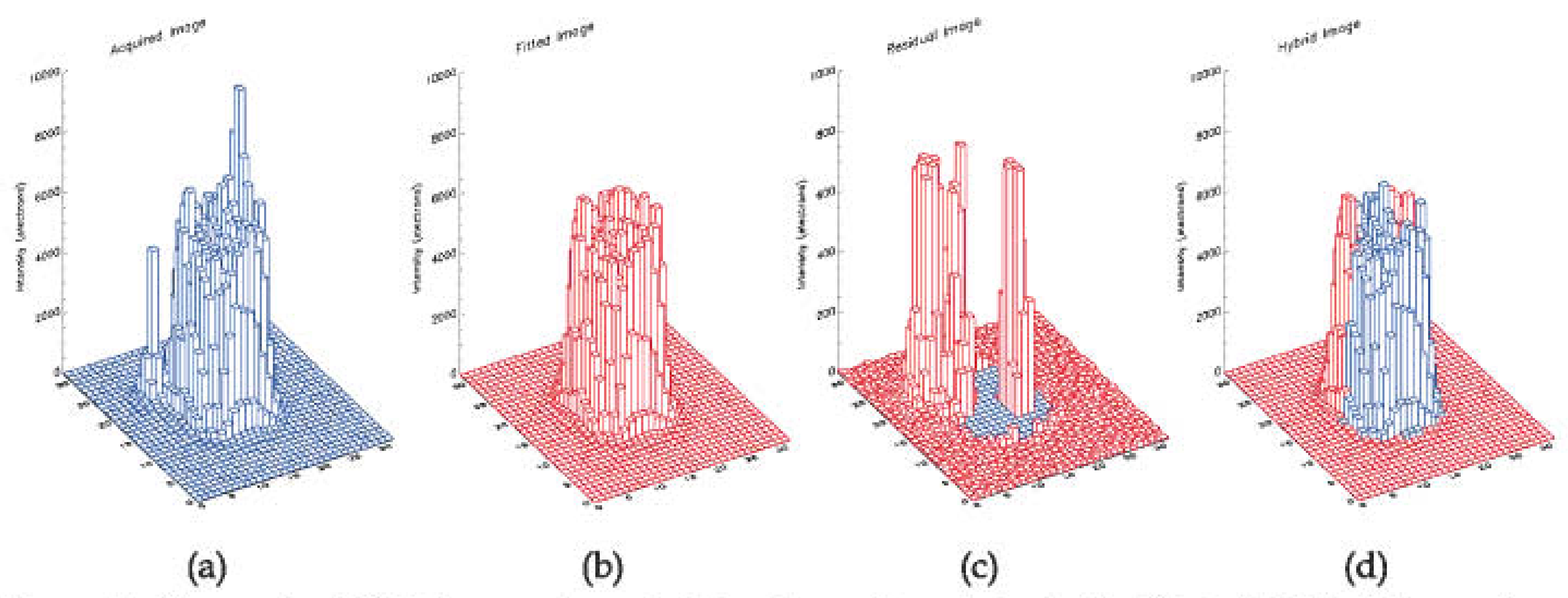


Figure 3: (a) acquired CCD image, impacted by charged particles in the SAA; (b) fitted image from empirical high-resolution PSF, which is robust to particle impacts and attitude jitter; (c) total noise in (a), composed by impacts, Poissonian, background and readout noises (red); (d) final hybrid image, which incorporates high SNR central pixels in the acquired image (in blue) and low uncertainty edge pixels in the fitted image (in red), thus eliminating impacted and/or high uncertainty pixels, and increasing the global SNR.

## Preliminary Results

Pinheiro da Silva [1], using MOST real data [2], has obtained important preliminary results , which indicate this methodology may achieve better performance than mask-only and psf-fitting-only photometries can achieve (Figure 4), thus adding important gains in photometric precision and increase the imaging duty cycle from 91% up to 97% in the CoRoT mission, enabling robust and more accurate data exploitation.

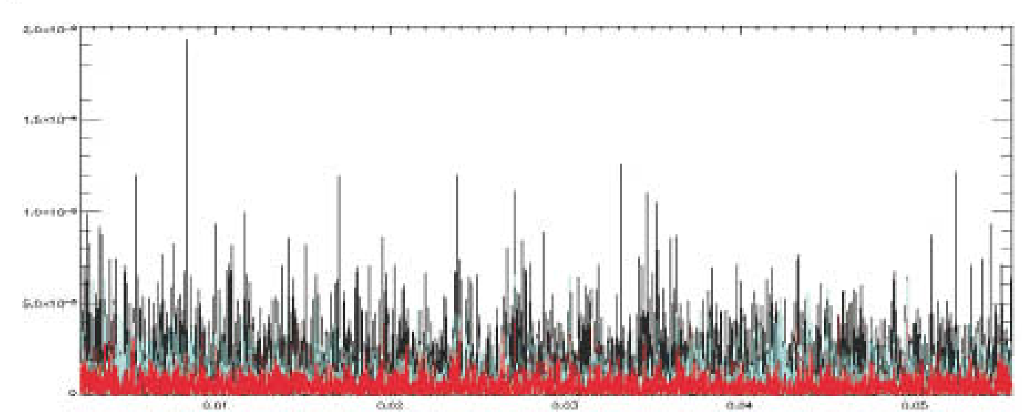

Figure 4: Power spectrum of a photometric signal from MOST. Mask-only (black), psf-fitting-only (cyan) and hybrid (red) photometries are compared. White noise is lowered probably down to photon noise limit.

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**References**

[1] Pinheiro da Silva L., A strategy for fitting photometry on defocused stellar images, Corot Brazil Workshop II, Ubatuba, 2006.

[2] Walker, G., Matthews, J., Kuschnig, R., et al. 2003, The MOST Asteroseismology Mission: Ultraprecise Photometry from Space, PASP, vol. 115

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