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BRITE-Constellation: Simulation of Photometric Performance

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Abstract

BRITE (BRIght Target Explorer) is a satellite mission dedicated to survey the sky, measuring the brightness and temperature variations of the brightest stars. In order to evaluate the expected performance of the science payload, a detailed simulation of the camera and the optical system has been performed. The results confirm that the SNR specified in the mission requirements can be achieved.

Science Instrument

The science payload of the satellite (Figure 1) consists of a five-lens telescope with an aperture of 30 mm and the interline CCD detector KAI 11002-M (Table 1) from Kodak with 11 megapixels, in combination with a baffle to reduce stray light. The photometer has a resolution of 26.52 arcseconds per pixel and a field-of-view of 24 degrees. The mechanical designs of the blue and the red instrument are nearly identical; only the dimensions of the lenses are slightly different (Figure 2).

Filters

The red edge of the effective wavelength range of the instrument is determined by the sensitivity of the detector and the blue edge by the transmission properties of the lens material. The filter design aims to generate the same number of electrons on the detector for a star of 10 000 K (average temperature for all BRITE target stars) for both systems. The blue and the red filters cover wavelength ranges of 390–460 nm and 550–700 nm respectively, both are assumed to have a maximum transmission of 95% (Figure 3).

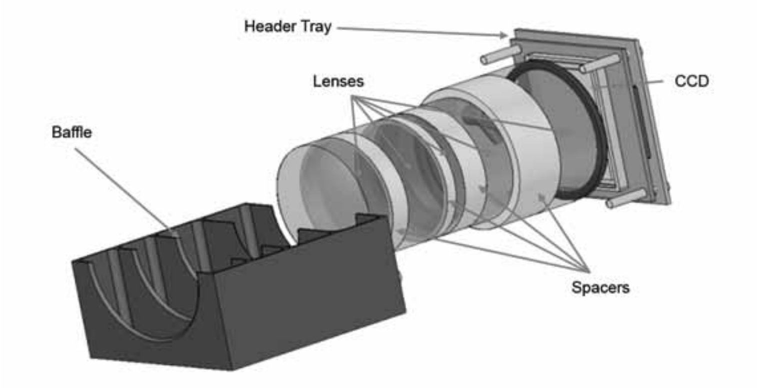

Figure 1: BRITE science instrument layout (optical cell and part of baffle removed for clarity).

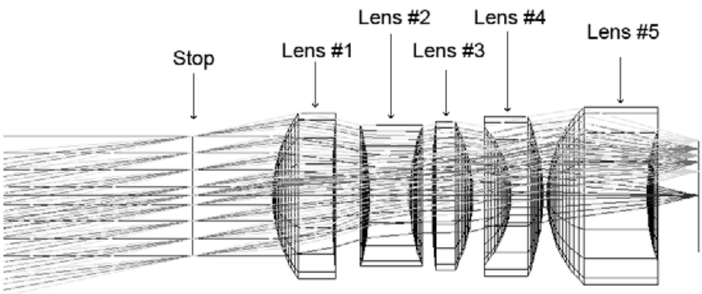

Figure 2: Optical design with external aperture stop configuration for the blue system.

Synthetic Fluxes

For the simulation of stellar fluxes, different model atmosphere codes were employed in order to compute a grid of fluxes for temperatures from 4000 K to 40000 K and for $\log g$ (cgs) from ≈ 1 to 5: MARCS (`www.astro.uu.se/marcs`) for cool stars, NEMO for intermediate-temperature stars and LLM for hot stars (`ams.astro.univie.ac.at/nemo`).

Figure 4 displays the flux distribution for a star with 10 000 K, $\log g = 4$ and an apparent visual magnitude of 4^m. The thick solid line indicates the stellar flux scaled to the aperture size of the telescope; the dashed line shows the quantum efficiency (QE) of the CCD detector. The solid lines represent the

Kodak KAI 11002-M CCD	
Imager size	37.25×25.70 mm
Number of pixels	4008×2672 (effective)
Pixel size	$9 \times 9\,\mu$m
Peak quantum efficiency	50%
Saturation signal	60000 e^-
Dark current	4 e^-/s/pixel
Read out noise	13 e^-/pixel
Power consumption	1 W

Table 1: CCD detector specifications.

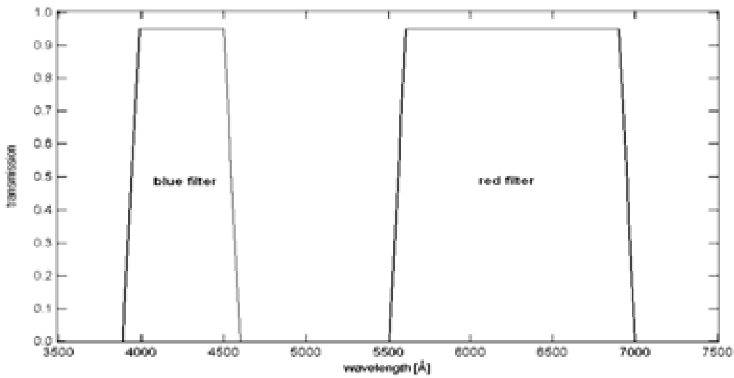

Figure 3: Transmission properties of the red and blue BRITE filters.

flux after folding with the transmission properties of the lenses, the QE and the filter functions.

Optical System Properties

The optical system of the science instrument was designed by Ceravolo Optics (`www.ceravolo.com`). To calculate the distribution of the stellar point-spread-function (PSF) on the detector plane, a grid of computed spot diagrams for different wavelengths and angles of incidence was used (Figure 5). Figure 6 shows a 32×32 pixel subframe with the PSF for the blue and the red system referring to a star with the flux distribution shown in Figure 4 and an angle of incidence of 7°. The total number of electrons is equal in both filters.

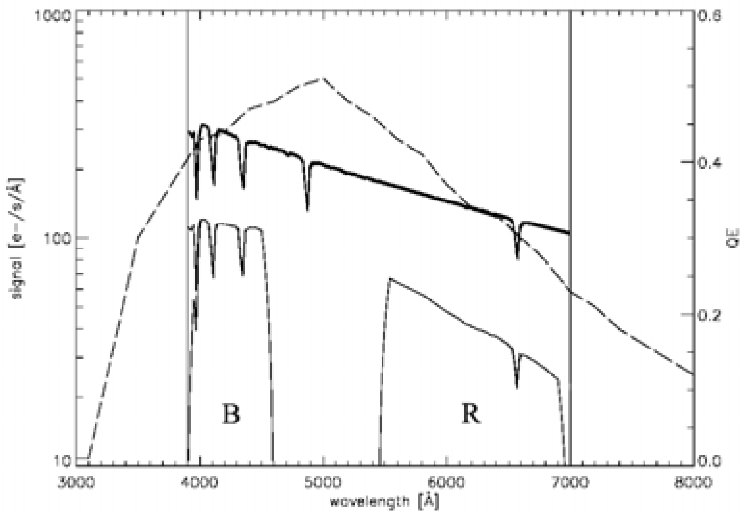

Figure 4: Flux distribution for a star with 10 000 K, $\log g = 4$ and a visual apparent magnitude of 4^m. The dashed line shows the QE of the detector.

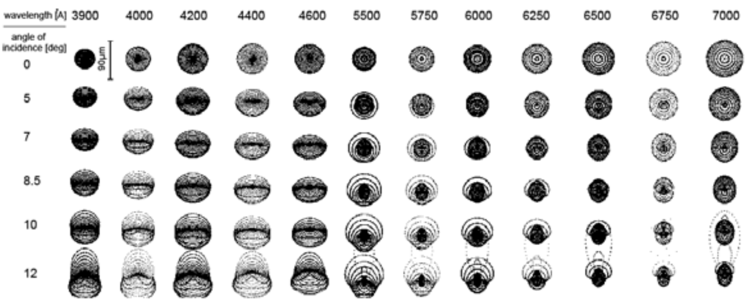

Figure 5: Spot diagram matrix for the blue and red filter system.

Synthetic Photometry

In order to perform a simulation of a time series, one has to account for errors in the pointing accuracy of the attitude control system (ACS) of the spacecraft. The mission requirement for the pointing error is 2–3 pixel rms with the goal of 1 pixel. Figure 7 shows a time-resolved simulation for the pitch and yaw error sampled in one-second steps for a 15-minute subset employing two different reaction wheel models developed by the University of Toront, Space Flight

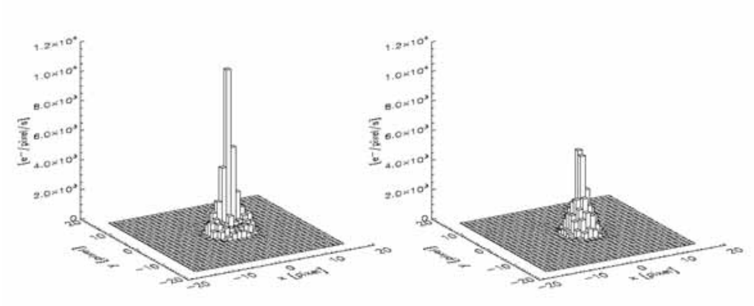

Figure 6: PSF of the blue (left panel) and the red (right panel) filter system for a star with 10 000 K, $\log g = 4$ and a visual apparent magnitude of 4^m, without jitter and a 7° angle of incidence for the optical system.

Labs (UTIAS/SFL). The resulting pointing accuracy is one and two pixels, respectively.

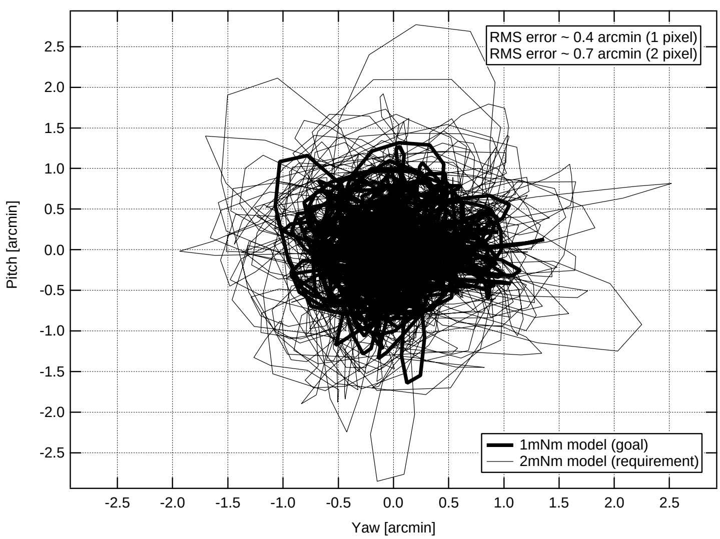

Figure 7: Pitch and yaw pointing errors (satellite jitter) simulated for 15 minutes in one second steps.

To avoid saturation of the CCD, the maximum exposure time for a star is limited by the intensity of the brightest pixel of the PSF. Figure 8 shows the maximum exposure times for the blue and the red filter system for a grid of stars with a 7° angle of incidence for the optical system. The black dots correspond to the main BRITE-Constellation targets with $V < 4^m$. It shows that a majority of the stars saturates at exposure times larger than one second.

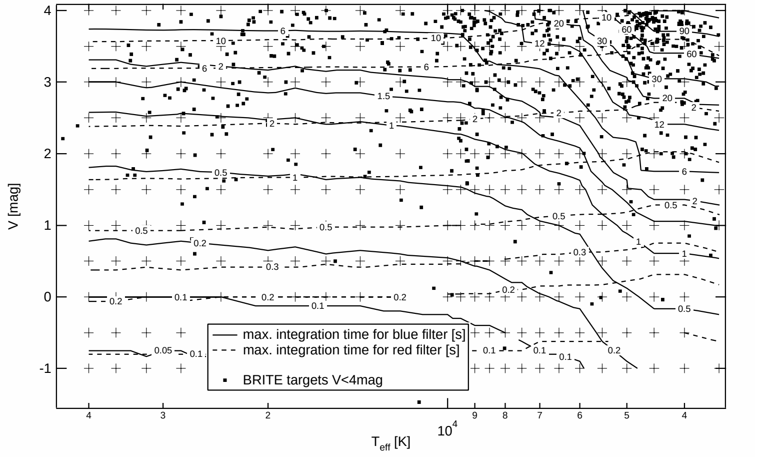

Figure 8: Maximum exposure times in seconds for the brightest pixel in the PSF for a grid of stars (black cosses) for the blue and the red filter with a 7° angle of incidence for the optical system.The dots correspond to the stars from the BRITE-Constellation input catalog.

The simulation of the expected SNR assumes a dark current of 4 e$^-$/pixel/s, a readout noise of 13 e$^-$/pixel and a sky background of 18 mag/arcsec^2 corresponding to 141 e$^-$/pixel/s for the red system and 99 e$^-$/pixel/s for the blue system. For each grid point, the maximum possible exposure time (5/6 of the saturation level) was used, and a readout gap of one second between consecutive exposures was assumed. Figures 9 and 10 show the resulting SNR for different spectral types. The thin black line is a histogram of the stars from the BRITE-Constellation input catalog.

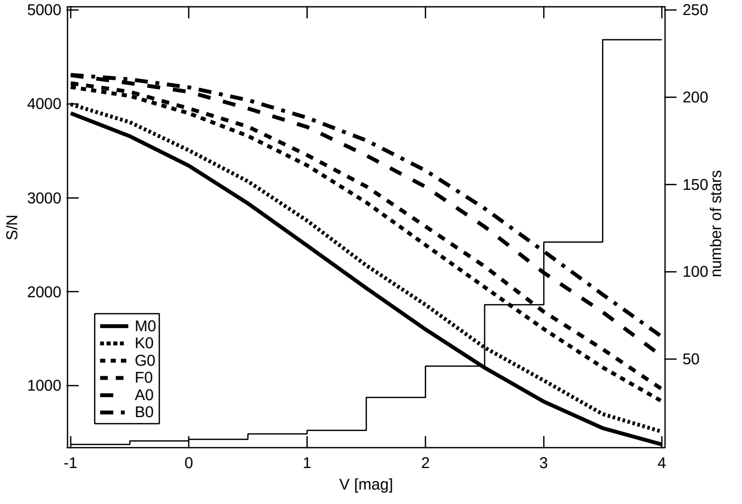

Figure 9: Estimated SNR for one minute of stacked frames with optimum exposure times for the blue system. The thin black line refers to a histogram of the stars from the BRITE-Constellation input catalog.

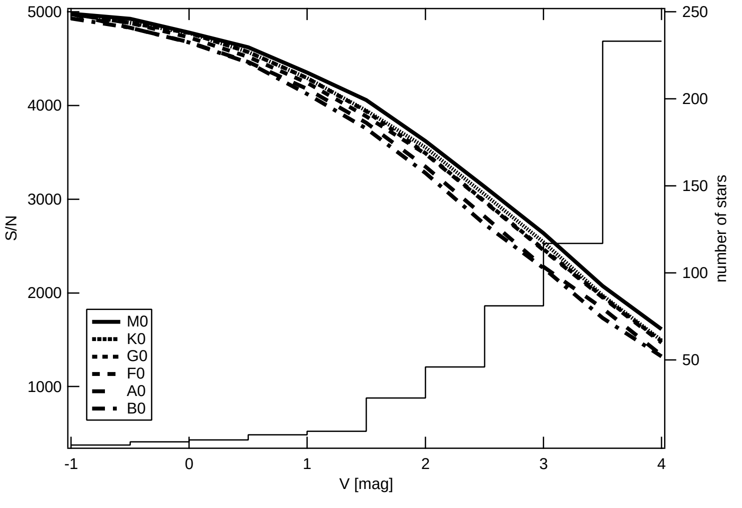

Figure 10: Same as Figure 10 for the red system.

Conclusion

In order to simulate the expected performance of the science instrument and to validate the specified mission requirements, a simulation has been performed. It shows that the mission requirement of an S/N of 1000 for a star of 3.5^m can be reached for 15 minutes of observation during one orbit.

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