Dependable Computing for Miniaturized Satellites

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Dependable computer design for space use up until now primarily relied upon radiation tolerant special purpose hardware. Especially in miniaturized satellite projects, the size and cost of such special purpose hardware is prohibitively high often making their use entirely unfeasible. Over the past 2 years, protective architectures to enable fault-tolerant computing aboard spacecraft have been researched, enabling dependable computing and data storage aboard miniaturized satellites. As a result, a fault-tolerant base for future research on advanced compute dependability concepts has been enabled.

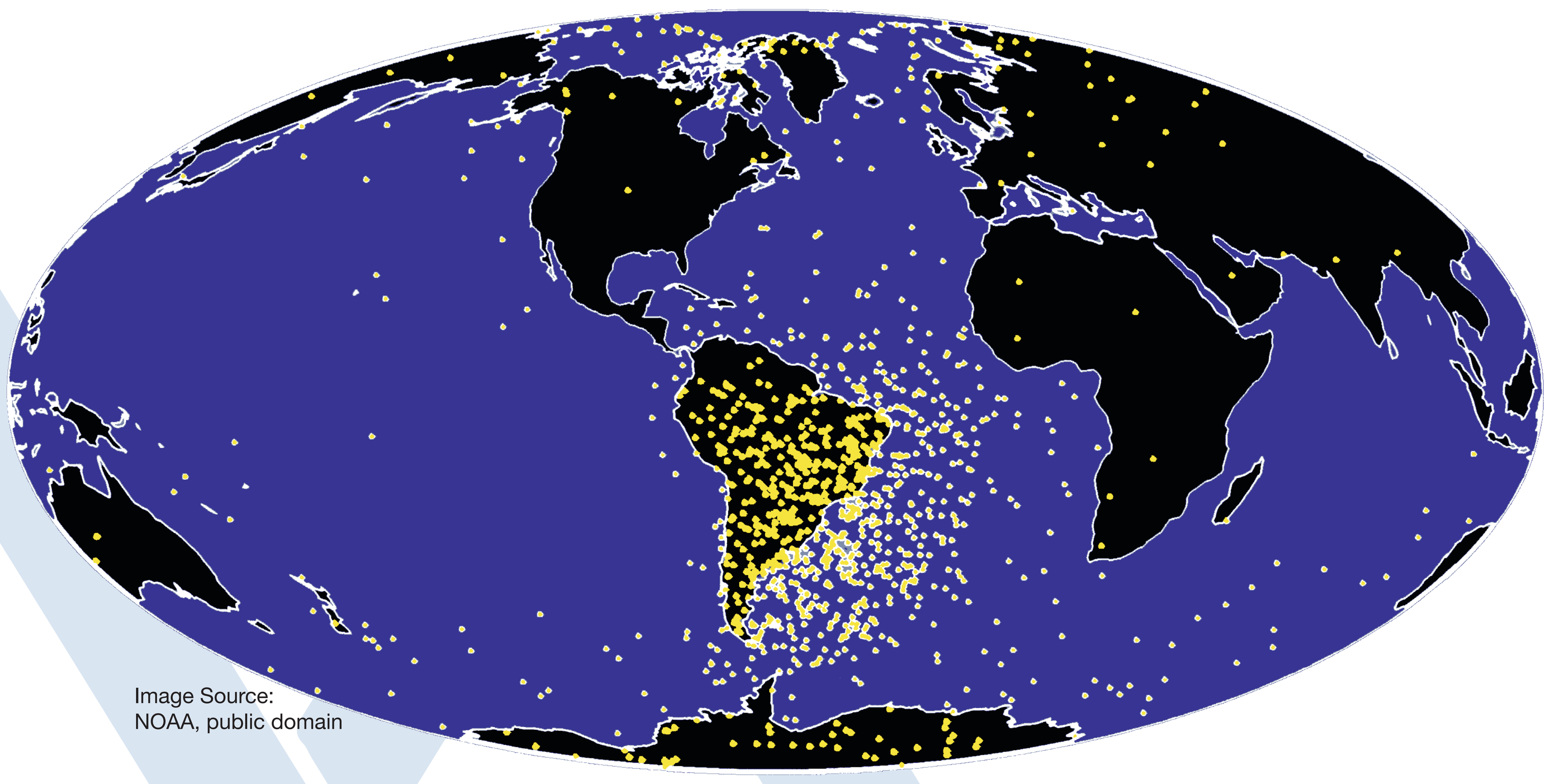

Figure 4: Event upsets in memory measured by the UOSAT-2 microsatellite showing the effect of the increased energetic particle intensity in the South Atlantic region.

Instrumentation aboard Miniaturized Satellites:

Technological evolution nowadays allows for a high level of miniaturization aboard spacecraft. Therefore, miniaturized satellites have become increasingly popular, as various instruments can be adapted to such smaller vessels as well. Nowadays, even nano- and picosatellites can host scientific payload. CubeSats are currently the most popular nanosatellite form factor due to their cost efficiency and ever increased system performance. They can be stacked, with a single-unit (1U) cube of 10x10x10 cm and 1.33 kg requiring a budget of about 300.000 EUR/USD for construction, testing and launch. The 2U CubeSat MOVE-II is currently under development at TUM and scheduled for launch in 2018 (Fig 1). The predecessor vessel First-MOVE was launched into LEO in 2013.

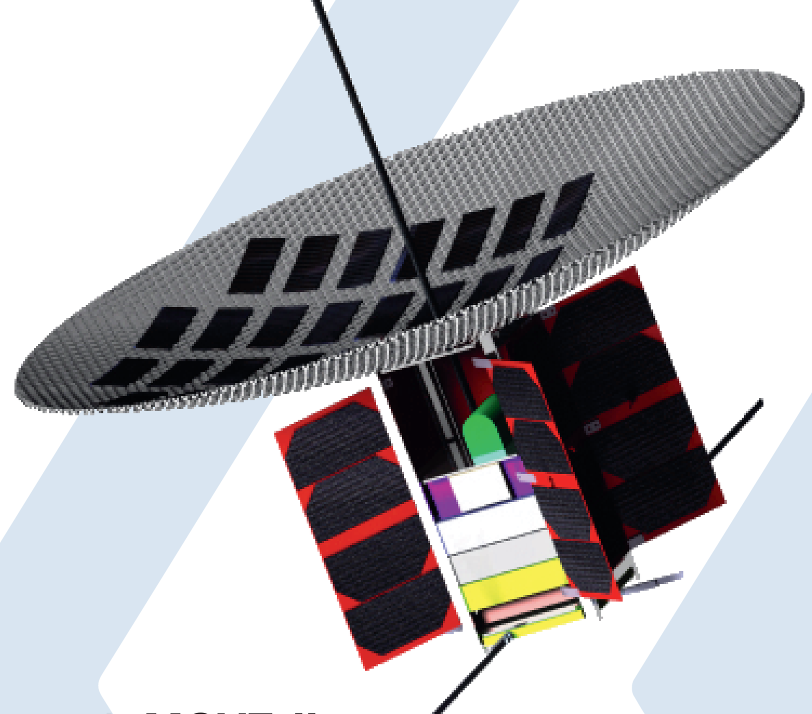

Figure 1: MOVE-II

A potential payload for MOVE-II is the AFIS detector (Fig 2), a particle detector developed at the Institute for Hadronic Structure and Fundamental Symmetries. This payload will measure the antiproton flux density within the South Atlantic Anomaly by tracing particles passing through multiple layers of scintillating material (Fig 3). To collect a scientifically meaningful amount of data, measurements must be conducted over at least 6 months.

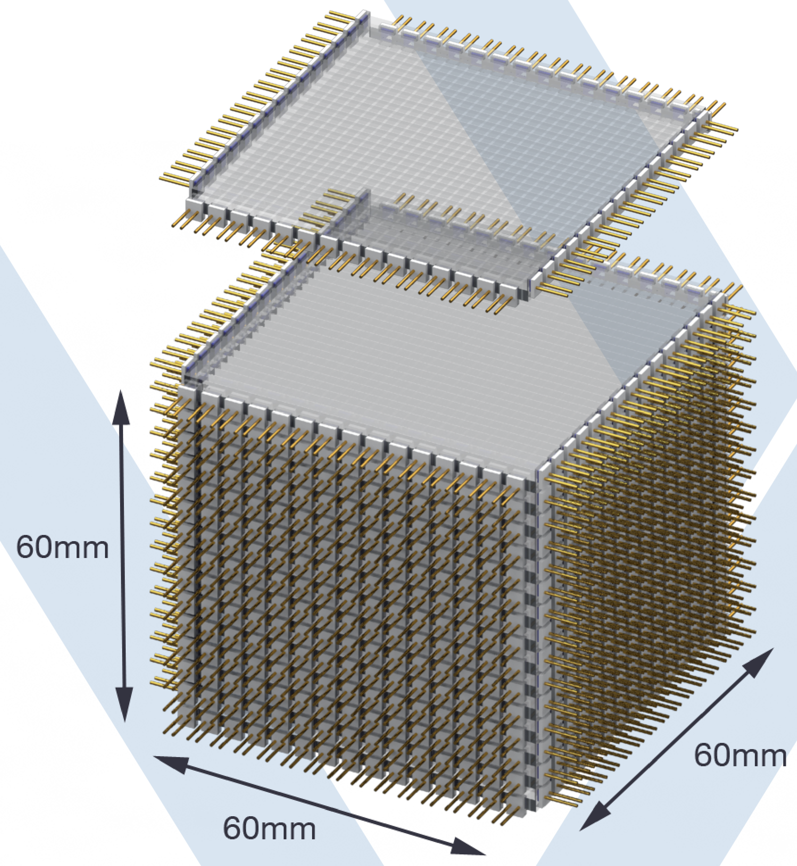

Figure 2: The AFIS detector's core.

While nanosatellite sophistication increases, reusability, dependability, and reliability remain low. In part, this is due to nanosatellites usually no longer being based upon radiation hardened special purpose hardware due to financial reasons, and restrictions regarding energy consumption, size and mass. Besides extreme temperature variations and the absence of atmosphere for heat dissipation, the impact of the near-Earth radiation environment (Fig 4) must be considered in space computing. Electronical components, especially higly scaled ASICs (e.g. processors) and memory technologies (e.g. SRAM, Flash) vary regarding the energy-threshold necessary to induce an effect and the type of effect caused. Symptoms usually include temporary data corruption and functional interrupts, but can also result in permanent defects crippling on-board electronics.

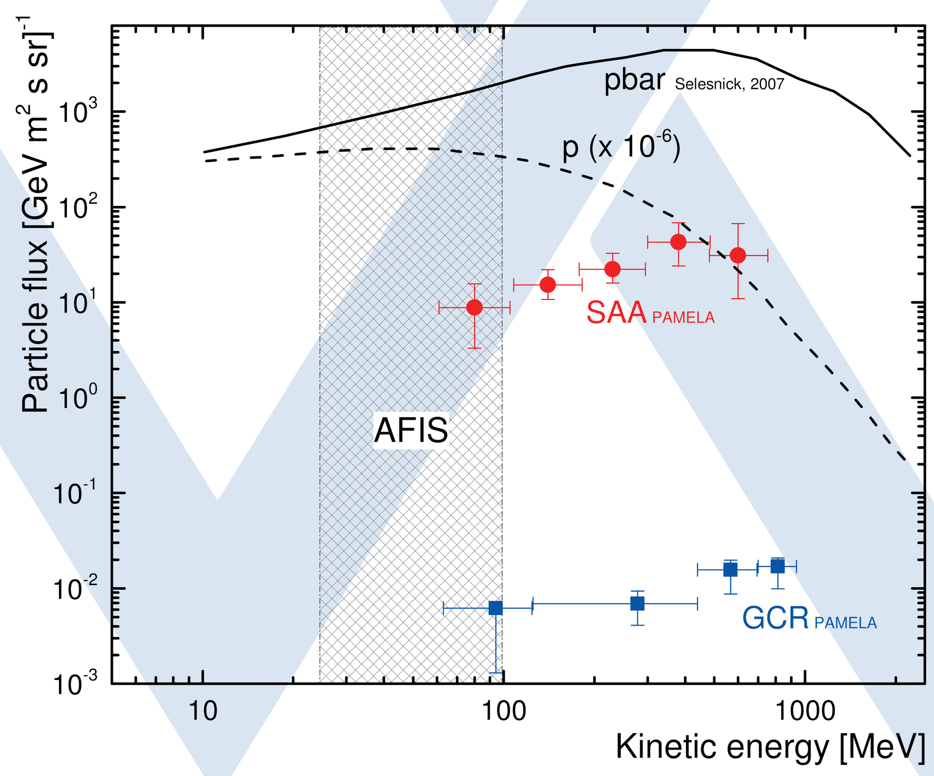

Figure 3: The detector will be able to measure the antiproton flux in the range of the shaded region. Model data (black) and PAMELA measurements (red taken transitting the SAA, blue taken outside) are plotted as well.

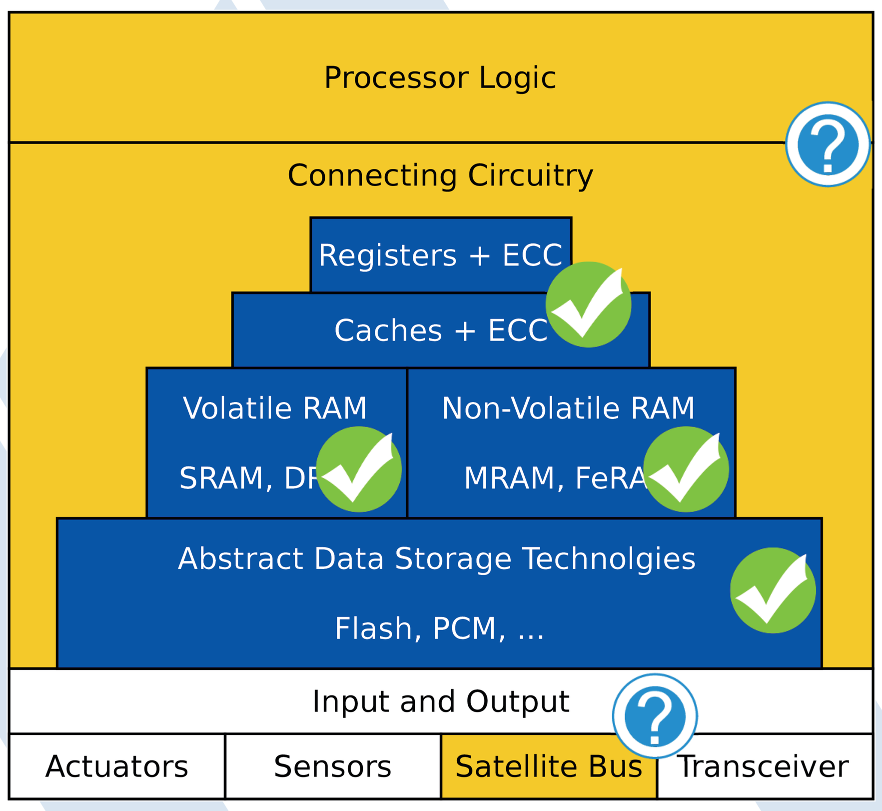

Figure 5: Component view of an on-board computer, with concluded research (blue), current & future research (yellow).

Research & Results:

Neither pure hardware- nor software-side measures can individually guarantee sufficient system consistency with modern highly scaled components. However, a combination of hardware and software measures can drastically increase system dependability, even for missions with a long duration. Over the past 2 years, protective architectures to enable fault-tolerant computing aboard spacecraft have been researched, enabling dependable computing and data storage aboard miniaturized satellites (Fig 5).

System dependability can not be assured unless program code and required supplementary data can be stored consistently and reliably aboard a spacecraft, thus initial research was focused on storage dependability. To protect critical system data stored in non-volatile memory (e.g. MRAM), a fault tolerant radiation robust file system for space use - FTRFS - has been developed (Fig 6). To take advantage of highly-scaled NAND-Flash mass-memory in long-term scientific missions such as JUICE and Euclid, we designed a novel storage architecture (Fig 7) which can handle radiation effects in flash memory (Fig 8). Another protective concept was developed for volatile S/DRAM, which can be implemented fully using only commercially available hardware.

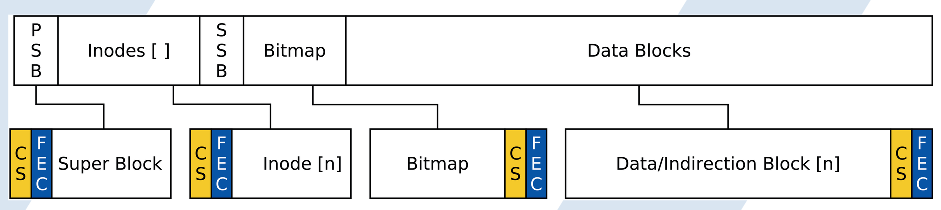

Figure 6: The layout of FTRFS with integrity assurance data colorized.

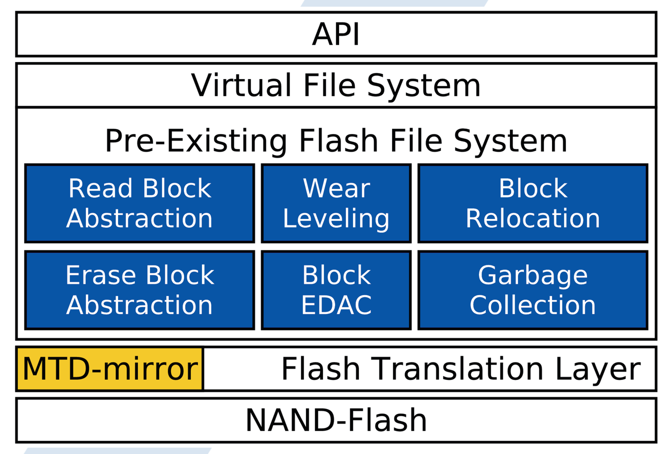

Figure 7: The MTD-mirror architecture

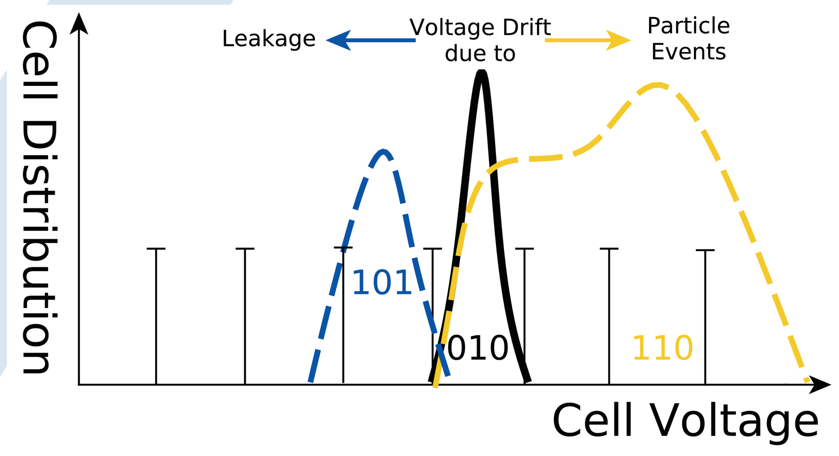

Figure 8: Radiation effects and cell leakage on modern Flash memory.

Future research will be directed towards next generation compute dependability based on an FPGA platform. Software side validation will be utilized to assure computational correctness and health of the programmed logic to increase voting accessibility and verifiability. The system (Fig 9) will be able to adapt to different requirements during a mission, offering high reliability or increased performance on demand. Once faults within the logic or control flow have been detected, the system will first countermand soft errors in the array by performing partial and later full reprogramming of the affected device. Ultimately, the architecture can also enable re-scheduling of permanently defective compute logic. The required voting logic can either be self-contained within the component or implemented separately to increase verifyability.

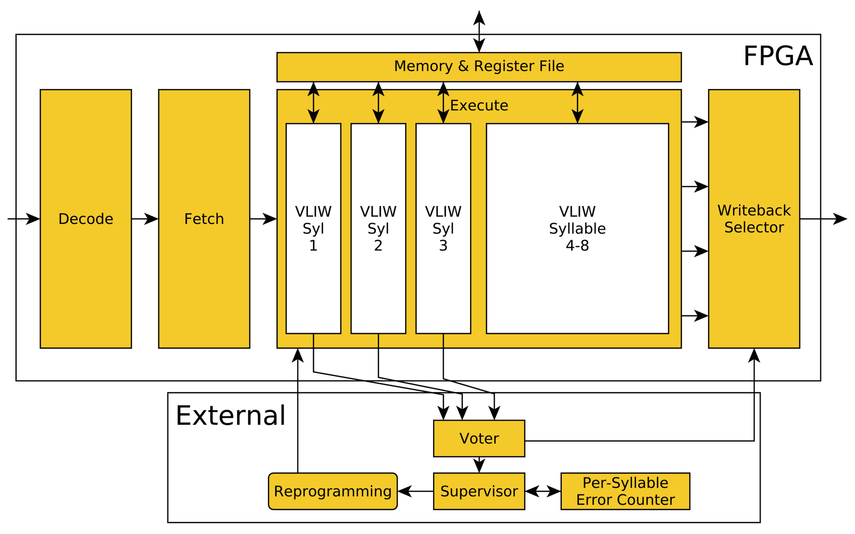

Figure 9: Idealized version of a self validating FPGA based processor.

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