Onboard Data Processing for the Photospheric Magnetic Field Imager: Efficient Data Reduction Aboard ESA's VIGIL Mission

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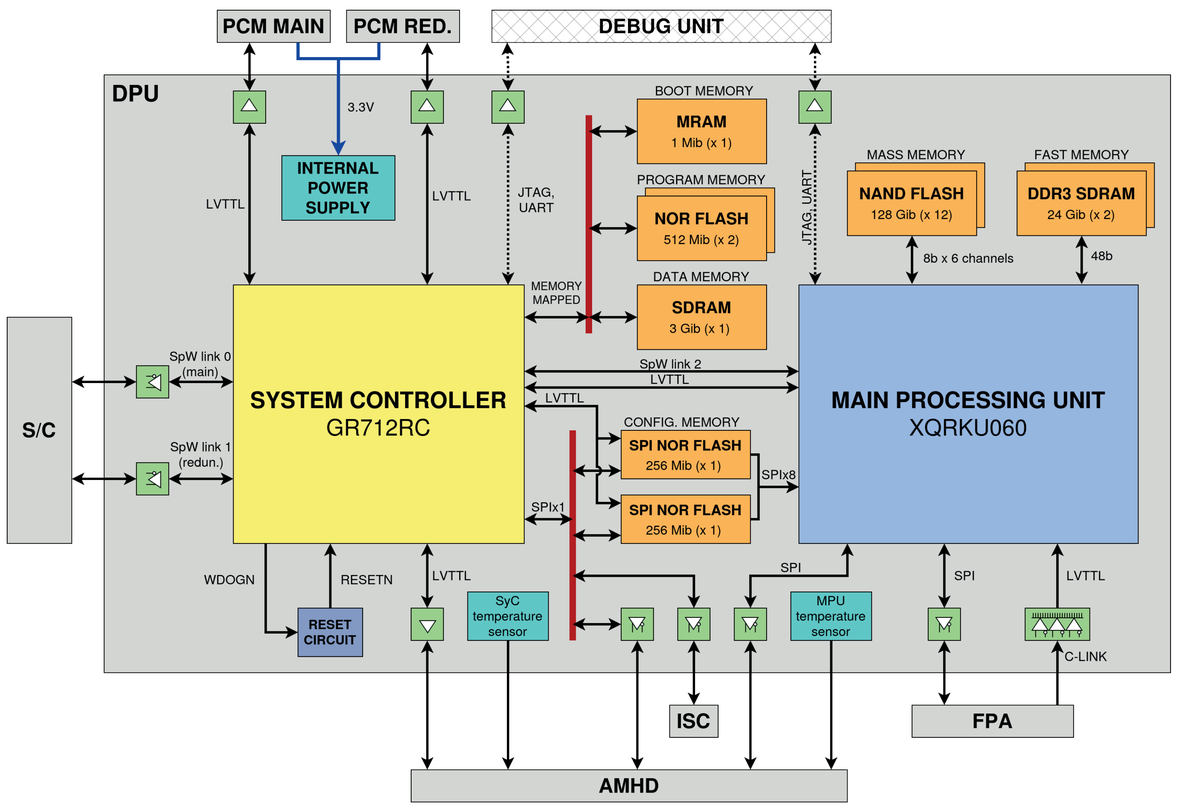
What Is the Photospheric Magnetic Field Imager?

The Photospheric Magnetic Field Imager (PMI) is one of the payload instruments aboard the European Space Agency's (ESA) VIGIL mission. It provides vector magnetograms and tachograms of the solar photospheric plasma as valuable data for space weather diagnostics.

The PMI instrument consists of an electronics unit and an optics unit, which are connected through a harness. The electronics unit contains a specialized digital processing unit (DPU), responsible for onboard data processing. It includes a system controller (SyC)—implemented in a GR712RC processor—and a main processing unit (MPU), based on a space-grade AMD Kintex® UltraScale™ XQRKU060 FPGA. The DPU also includes various memory modules and external interfaces.

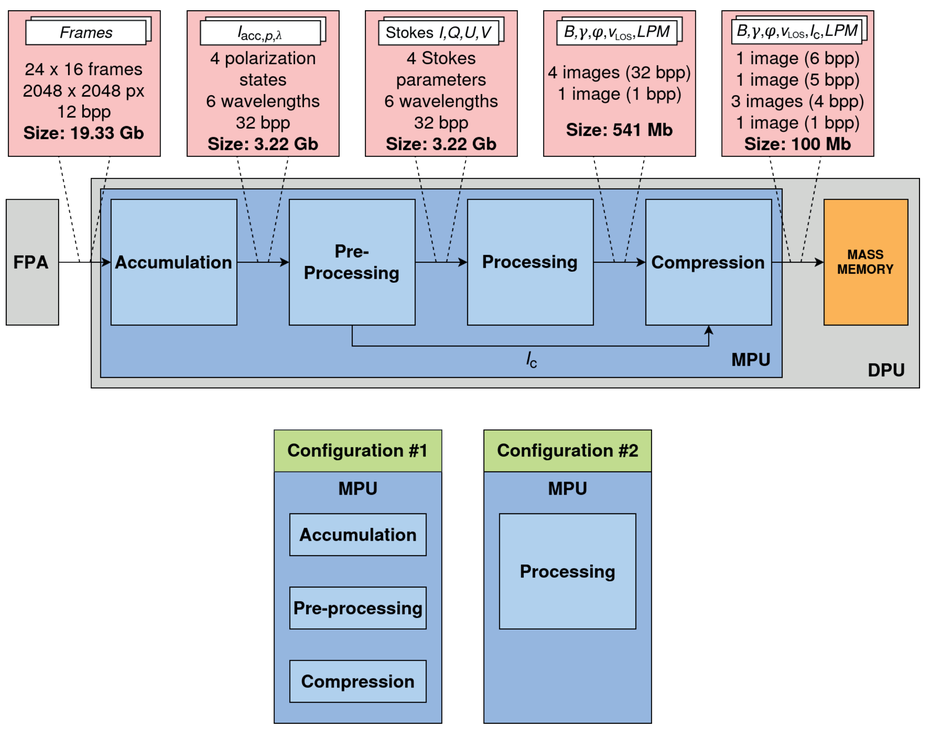


Why Do We Need Onboard Data Processing?

The telemetry limitations of the mission—located at 1 au from Earth at the L5 Lagrange point—the requirement for continuous 24/7 monitoring of the Sun's photospheric vector magnetic field and line-of-sight velocity, and the need for low-latency (20 min) and high-cadence (30 min) data products drive the implementation of a sophisticated onboard data reduction process. Additionally, partial scientific analysis is also performed onboard to minimize the size of the data products.

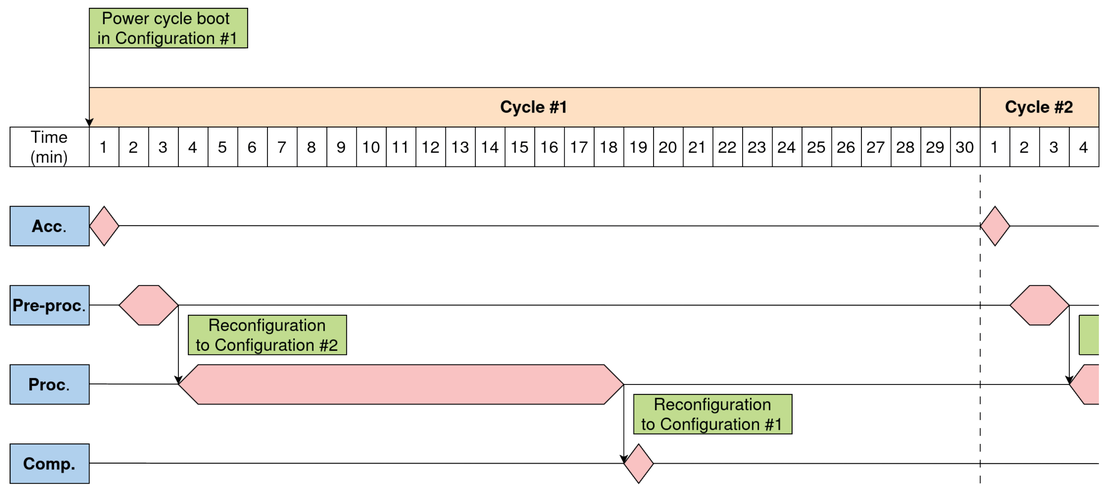
In its nominal observational mode, PMI produces 19.33 Gbit of data every 30 minutes, consisting of 24 images (four polarization states at six wavelengths) with a resolution of 2048 × 2048 pixels and a depth of 12 bits per pixel. Each image is formed by accumulating 16 camera frames during the initial processing stage. Through onboard processing, this data volume is significantly reduced to around 100 Mbit per dataset. The final dataset includes five maps (B, γ, φ, v_{LOS}, and I_C) at 2048 × 2048 px resolution at a maximum of 6 bit per pixel, along with a low-polarization mask image (*LPM*) at 2048 × 2048 px resolution at 1 bit per pixel.

To accomplish this functionality, the MPU processes data intensively using multiple processing blocks distributed across two FPGA configurations, reconfigured in flight.

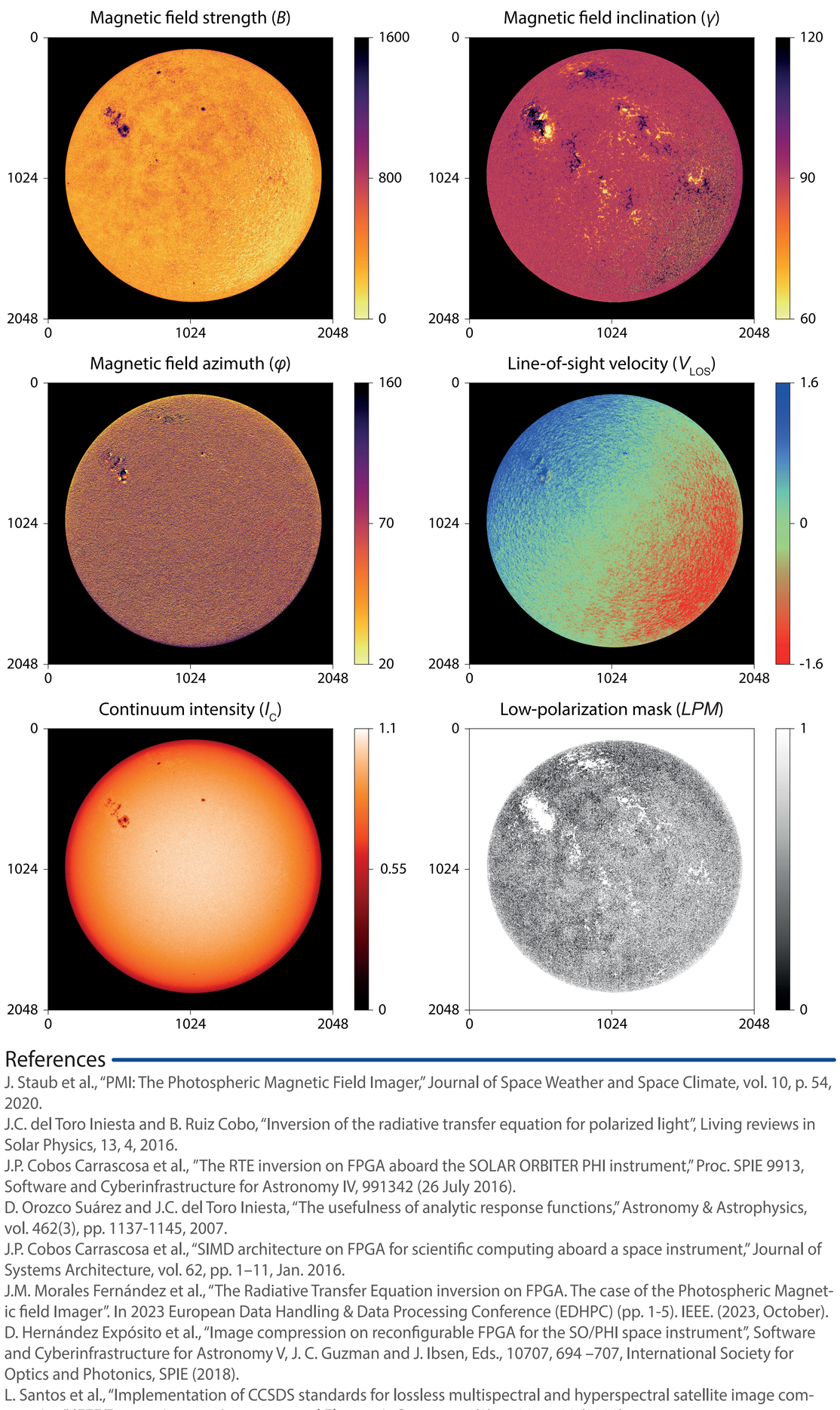


Onboard Pipeline

Accumulation is carried out at minute 1 of every 30-minute cycle. Then, pre-processing is performed at minutes 2 and 3, providing the Stokes parameters to the following processing stages. Immediately after, processing performs the RTE inversion of the Stokes parameters, which lasts from minute 4 to 19. Finally, compression applies the CCSDS 122 algorithm to the data at minute 19. At minute 20, the nominal-mode data products are ready for the SyC to add headers and send them to the spacecraft.



Output Data Products



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Acknowledgments

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