Performance analysis of the SO/PHI software framework for on-board data reduction

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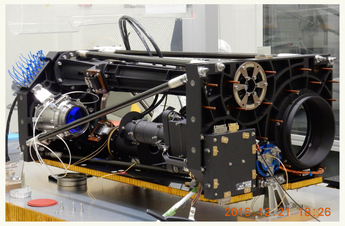
PHI on the Solar Orbiter

- Solar Orbiter: A mission to orbit the Sun in highly elliptical orbits, leaving the ecliptic.
- SO/PHI: The first solar imaging spectropolarimeter on a deep space mission.



SO/PHI flight model O-unit.

- Instrument principle: SO/PHI is aiming to infer photospheric $\vec{B}$, v_{LOS} and T by using Zeeman and Doppler effects. It takes time-series of images sampling the FeI 6173 Å absorption line at 6 wavelengths, in 4 polarisation states.

Sampling of the absorption line by SO/PHI.

- To meet some of the challenges imposed by SO, i.e dynamic environment and low data rates, SO/PHI does full on-board science data processing: data pre-processing (removing the instrumental effects and polarimetric demodulation), and infers the physical parameters (through the inversion of the radiative transfer equation, RTE).

References

[1] K. Albert, J. Hirzberger, D. Busse, et al.
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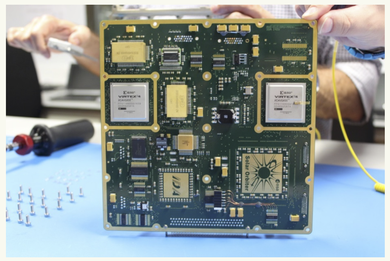
[2] S.K. Solanki, J.C. del Toro Iniesta, J. Woch, et al.
The Polarimetric and Helioseismic Imager.
Astronomy and Astrophysics, Submitted.

[3] Daniel Müller, Richard George Marsden, OC St Cyr, et al.
Solar orbiter.
Solar Physics, 285(1-2):25–70, 2013.

Data processing system



The SO/PHI DPU.

- The data processing is implemented on a custom DPU, accelerated with 2 FPGAs reconfigured in flight. Pipelines are built in the microprocessor, using FPGA functions.
- To save resources the pre-processing uses a 24.8 bits fixed point notation. To maintain accuracy the data is scaled at each step of the processing.
- Test pipeline:
  $S_\lambda(x,y) = D(x,y) \cdot [(I^{obs}_\lambda(x,y) - I^{dark}(x,y))/I^{flat}(x,y)]$

Preprocessing pipeline (fixed point notation)

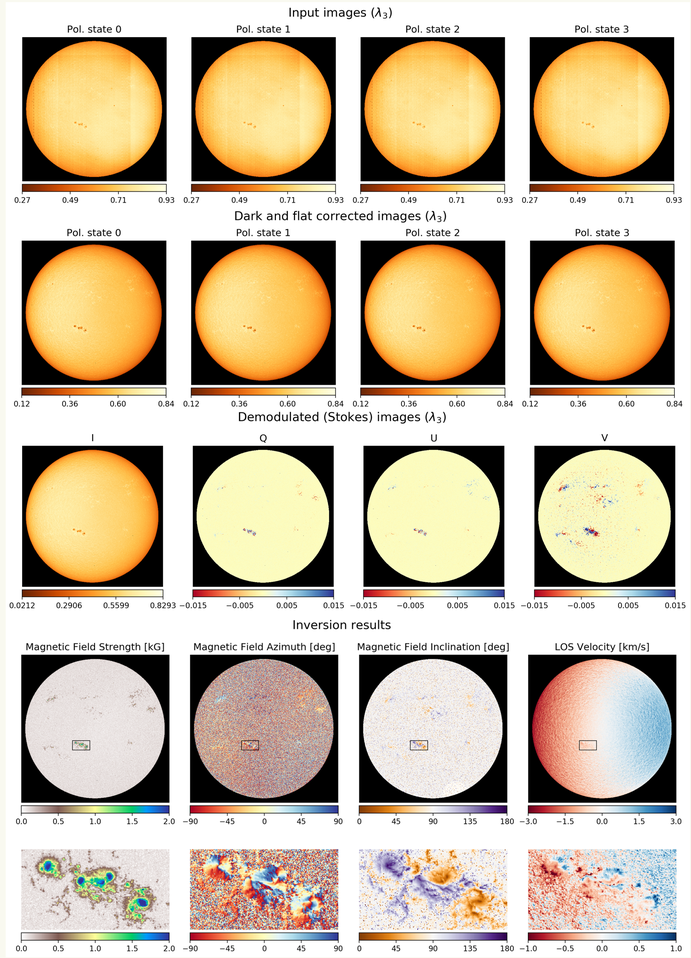
Load Target Dataset (**14.8 bits**)	
Scale Target Dataset to: 23.8 bits	
Target Dataset on: **23.8 bits**	Block 1: Load target
Target Dataset on: **23.8 bits**	
Load Dark Field (**23.8 bits**)	
Subtract Flat Field	
Result on: **23.8 bits**	Block 2: Dark field corr.
Target Dataset on: **23.8 bits**	
Load Flat Field (**2.8 bits**)	
Divide Flat Field	
Result on: **21.8 bits**	
Scale Target Dataset to: 23.8 bits	
Result on: **23.8 bits**	Block 3: Flat field corr.
Target Dataset on: **23.8 bits**	
Scale Target Dataset to: 12.8 bits	
Target Dataset on: **12.8 bits**	
Load Demodulation Matrix (**9.8 bits**)	
Matrix Multiplication: $M(4\times4)\cdot M(1\times4)$	
Result on: **23.8 bits**	Block 4: Polarimetric demod.

RTE inversion (floating point notation)

Data accuracy is controlled in the pipeline.

Science data processing

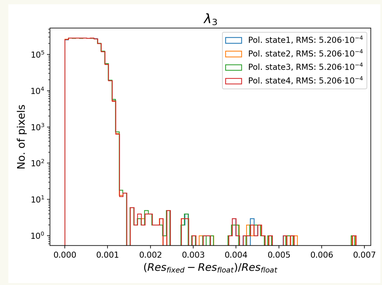
- The results of the SO/PHI pipeline are compared to reference pipeline results calculated in floating point.
- The inversion of the RTE is done on ground for an impression.



The input data, and the partial results of the tested pipeline.

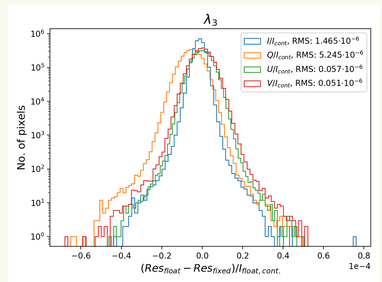
Results

- The flat field division induces uniform errors in the whole data set, with a $5 \cdot 10^{-4}$ RMS.



Histogram of errors after flat field division.

- The errors after the polarimetric demodulation decrease because in polarimetry we calculate the difference of signals. The requirement is 10^{-3} sensitivity. The error RMS is in the order of 10^{-6}.



Histogram of errors after polarimetric demodulation.

- The inferred physical parameters have inaccuracies with an RMS of 0.14 G, 2° and 0.04° in the $\vec{B}$ strength, azimuth and inclination (calculated over strong magnetic regions). The v_{LOS} error RMS is $7 \cdot 10^{-3}\,\mathrm{ms}^{-1}$ over the full disk.

Conclusions

- SO/PHI executes part of the data processing in fixed point notation to save resources.
- The fixed point notations introduce errors far below the instrument requirements, leaving a large margin for other error sources.
- The analysis of $\mathscr{F}$ domain processing is ongoing.

Acknowledgments

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