

Metadata and its importance in SO/PHI's on-board data processing K. Albert,¹ J. Hirzberger,¹ D. Busse,¹ P. Gutierrez-Marques,¹ and M. Kolleck¹ ¹Max Planck Institute for Solar System Research



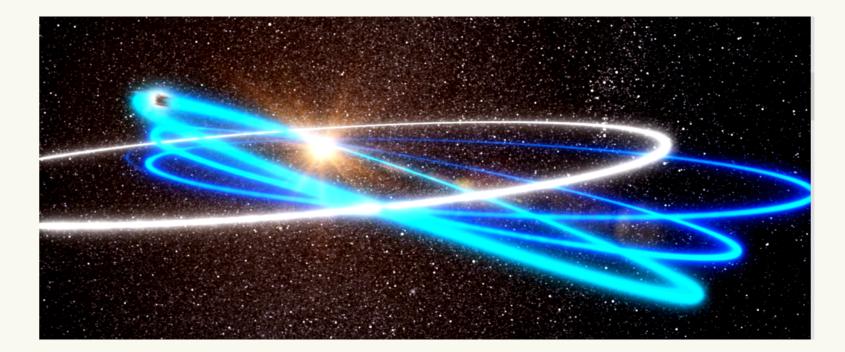
Solar Orbiter and the Polarimetric and Helioseismic Imager

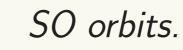
Solar Orbiter: Orbits the Sun between 1 AU and 0.28 AU,

 with an inclination from ecliptic: up to 33° (extended mission).
 SO/PHI: Imaging spectropolarimeter at the Fel 617.3 nm absorption line. Two optical paths: FDT (2°) and HRT (0.28°, 100 km/pix at 0.28AU). Extensive on-board processing: science data reduction, instrument characterisation and operational calibration. See [3].

Full on-board data reduction:

24 raw images $(6 \times \lambda, 4 \times \text{Pol}) \rightarrow 5$ physical quantities $(\vec{B}, v_{\text{LOS}}, T)$, by applying the on-board created calibration data and inverting the RTE.







SO/PHI flight model O-unit.

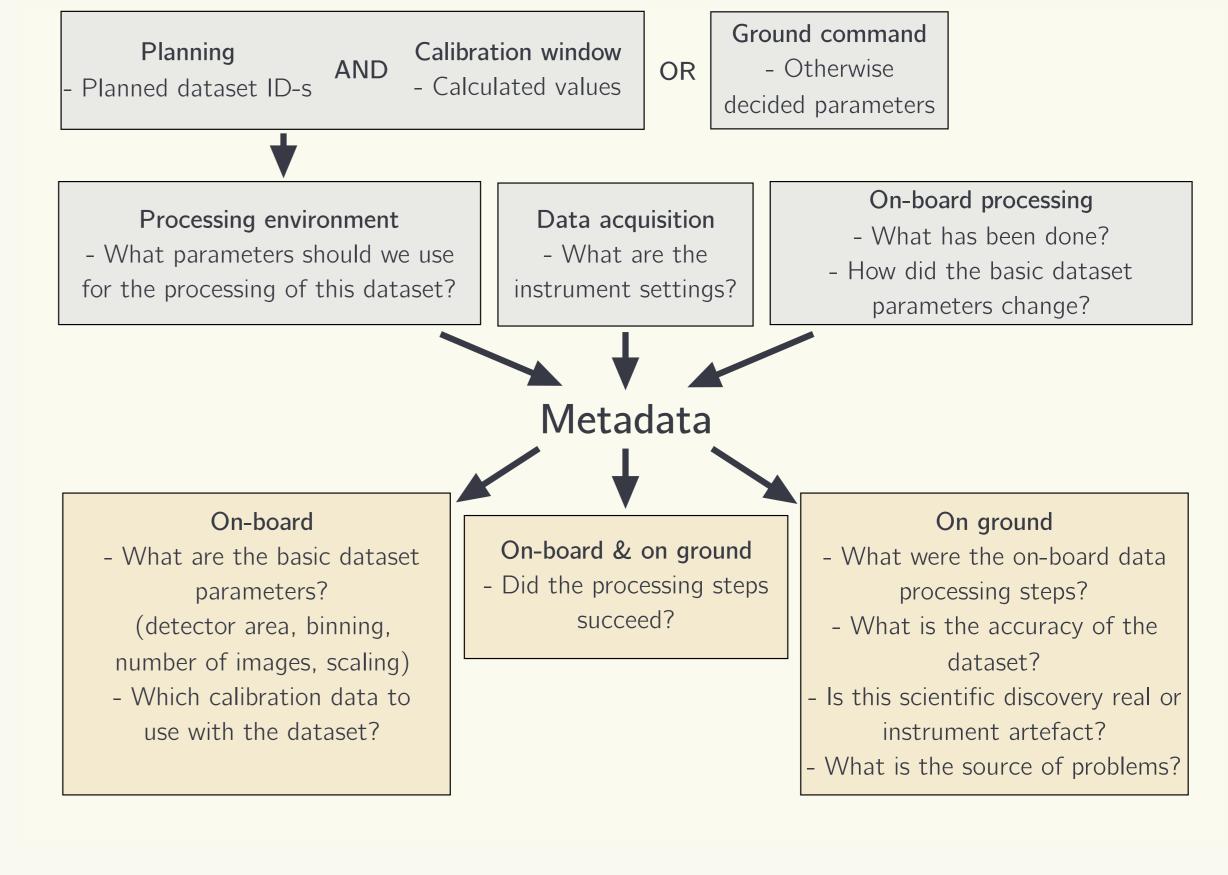
Data processing pipelines

- Functions: science data reduction, instrument characterisation and operational parameter calculation.
- Autnomy: little interaction with pipeline due to long command-response turnaround and limited TM/TC volume.
- Available hardware: 2 reconfigurable FPGAs to accelerate image processing, 1 System Controller GPU for control and back-up implementation.
- Requirements: science ready datasets as result, flexible pipelines, fixed point arithmetics (where possible).

| Image Acquisition | |
|--|---|
| | Data processing pipeline |
| Dark Field Correction | Data pre-processing pipeline |
| Flat Field Correction | |
| Impaired pixels detection - | Binning Cropping Primary processing |
| Correction of PSF | Correction for interference fringes Deconvolution |
| Polarisation demodulation | |
| Cross-talk correction | |
| Classical estimates and RTE inversion | |
| Compression | Basic steps Optional steps |

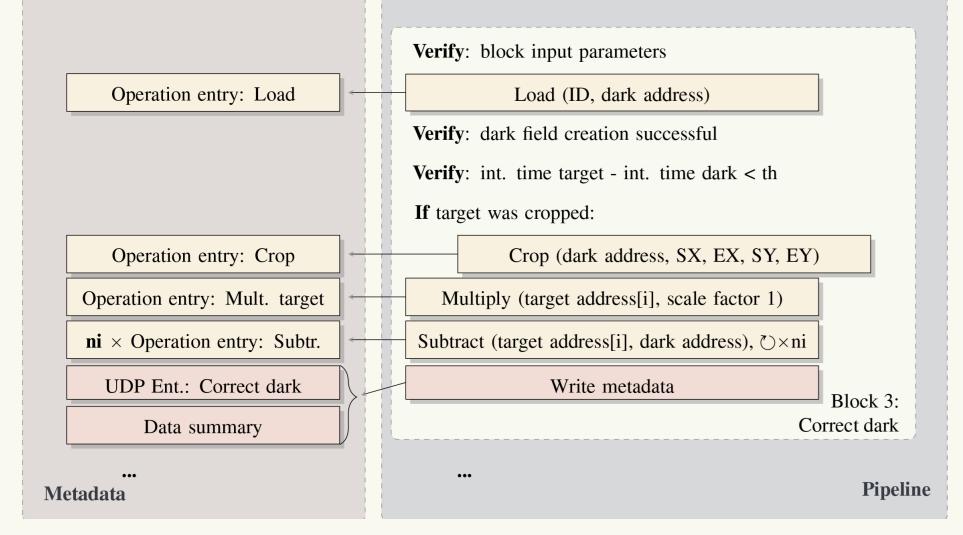
Science data processing of SO/PHI.

Metadata System



Metadata sources and usage.

Example metadata collection

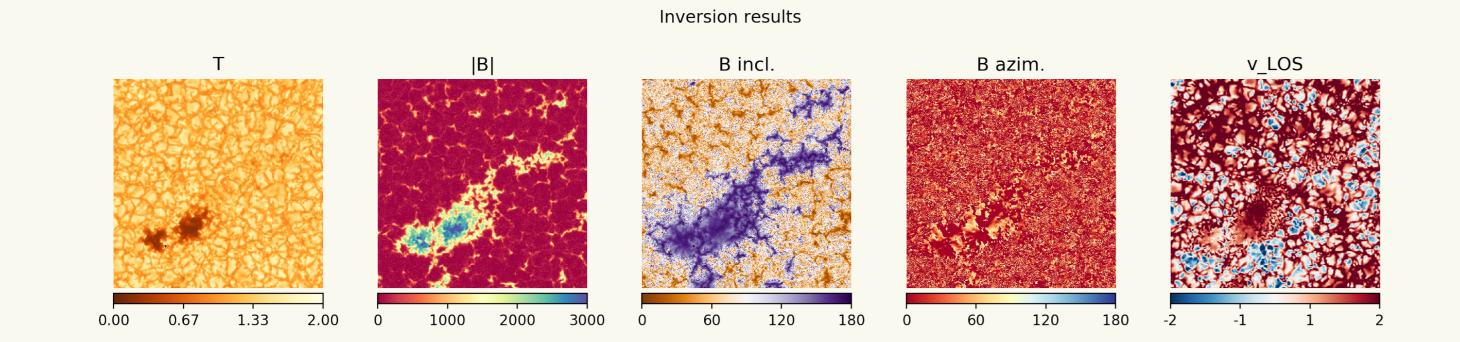


| Select | Record Time A24 | OperationID A13 | OperationReturn A4 | MemAddress1 A10 | MemAddress2 A10 | MemAddress3 A10 | Rows A5 | Columns A5 | Scalar1 A11 | Scalar2 A11 |
|--------|--------------------------|--------------------|-----------------------|--------------------|--------------------|--------------------|---------|------------|-------------|----------------|
| All | Time | | | | | | | | | |
| Invert | Modify | Modify | Modify | Modify | Modify | Modify | Modify | Modify | Modify | Modify |
| 5 | 2019-09-25 12:50:44.0000 | PROC_LOAD | 0 | 90170 | 2621440 | 0 | 512 | 512 | 0 | 0 |
| 6 | 2019-09-25 12:50:44.0000 | PROC_F_MUL_S | 0 | 26214400 | 0 | 26214400 | 512 | 512 | 131072 | 0 |
| 7 | 2019-09-25 12:50:44.0000 | PROC_F_SUB_I | 0 | 0 | 26214400 | 0 | 512 | 512 | 0 | 0 |
| 8 | 2019-09-25 12:50:44.0000 | PROC_F_SUB_I | 0 | 1048576 | 26214400 | 1048576 | 512 | 512 | 0 | 0 |
| 9 | 2019-09-25 12:50:44.0000 | PROC_F_SUB_I | 0 | 2097152 | 26214400 | 2097152 | 512 | 512 | 0 | 0 |
| 10 | | | | | | | | | | |
| 11 | 2019-09-25 12:50:45.0000 | PROC_F_SUB_I | 0 | 22020096 | 26214400 | 22020096 | 512 | 512 | 0 | 0 |
| 12 | 2019-09-25 12:50:45.0000 | PROC_F_SUB_I | 0 | 23068672 | 26214400 | 23068672 | 512 | 512 | 0 | 0 |
| 13 | 2019-09-25 12:50:45.0000 | PROC_F_SUB_I | 0 | 24117248 | 26214400 | 24117248 | 512 | 512 | 0 | 0 |

Implementation details of dark field correction module, one of the pipeline blocks executed during science data processing.

Operation entries in the metadata, collected during the run of dark field correction. (Excerpt.)

Example metadata based error search



| Select | Record Time A24 | BlockReturn A4 | BlockName A5 | OperandID A10 | FreeParameter1 A11 | FreeParameter2 A11 | ImageEndIndex A3 | RowEnd A5 | ColumnEnd A5 |
|------------|--------------------------|-------------------|-----------------|------------------|--------------------|-----------------------|---------------------|-----------|-----------------|
| Ali Invert | Time Modify | Modify | Modify | Modify | Modify | Modify | Modify | Modify | Modify |
| III¥CI (| Mounty | Moarry | Mouny | Mourry | Mounty | Mounty | Mounty | Mounty | I WOUT Y |
| 1 | 2019-09-25 12:50:43.0000 | 0 | LOAD | 90240 | 512 | 512 | 24 | 511 | 511 |
| 2 | 2019-09-25 12:50:44.0000 | 0 | DARK | 90270 | 8388608 | 0 | 24 | 511 | 511 |
| 3 | 2019-09-25 12:51:22.0000 | 0 | FLAT | 90280 | 4 | 0 | 24 | 511 | 511 |
| 4 | 2019-09-25 12:51:23.0000 | 0 | PIPE1 | 90240 | 0x7F | 0 | 24 | 511 | 511 |
| 5 | 2019-09-25 12:51:24.0000 | 0 | LOAD | 90240 | 0 | 0 | 24 | 511 | 511 |
| 6 | 2019-09-25 12:52:00.0000 | NANS | DEMOD | 90260 | 0 | 0 | 24 | 511 | 511 |
| 7 | 2019-10-01 12:10:55.0000 | 0 | NORM | 92240 | 49868192 | 0 | 24 | 511 | 511 |
| 8 | 2019-10-01 12:12:26.0000 | 0 | NANS | 92240 | 0 | 2048 | 24 | 511 | 511 |
| 9 | 2019-10-01 12:12:30.0000 | 0 | REOR1 | 92240 | 0x1FF | 1 | 25 | 511 | 511 |
| 10 | 2019-10-01 12:12:30.0000 | 0 | REOR1 | 92240 | 5 | 0 | 25 | 511 | 511 |
| 11 | 2019-10-01 12:18:26.0000 | 0 | INVER | 92240 | 1 | 0 | 6 | 511 | 511 |
| 12 | 2019-10-01 12:19:09.0000 | 0 | REOR2 | 92240 | 0x1FF | 1 | 5 | 511 | 511 |
| 13 | 2019-10-01 12:19:16.0000 | 0 | PIPE2 | 92240 | 0x7F | 0 | 5 | 511 | 511 |
| | | | | | | | | | |

| | RecordTime | BlockReturn | BlockName | OperandID | 📕 Free Parameter 1 | 📕 FreeParameter2 | 📕 ImageEndIndex | RowEnd | ColumnEnd | |
|--------|------------|-------------|-----------|-----------|--------------------|------------------|-----------------|--------|-----------|--|
| Select | A24 | A4 | A5 | A10 | A11 | A11 | A3 | A5 | A5 | |

| 0.0000 0.0033 0.0067 0.0100 | 0 1000 | 2000 3000 | 0 60 | 120 180 | 0 | 60 120 | 180 | -2 -1 | 1 | 2 |
|-----------------------------|--------|-----------|------|---------|---|--------|-----|-------|---|---|

| All 📕 | Time | | | | | | | | |
|--------|--------------------------|--------|--------|--------|----------|--------|--------|--------|--------|
| Invert | Modify | Modify | Modify | Modify | Modify | Modify | Modify | Modify | Modify |
| 1 | 2019-09-25 12:50:43.0000 | 0 | LOAD | 90240 | 512 | 512 | 24 | 511 | 511 |
| 2 | 2019-09-25 12:50:44.0000 | 0 | DARK | 90270 | 8388608 | 0 | 24 | 511 | 511 |
| 3 | 2019-09-25 12:51:22.0000 | 0 | FLAT | 90280 | 4 | 0 | 24 | 511 | 511 |
| 4 | 2019-09-25 12:51:23.0000 | 0 | PIPE1 | 90240 | 0x7F | 0 | 24 | 511 | 511 |
| 5 | 2019-09-25 12:51:24.0000 | 0 | LOAD | 90240 | 0 | 0 | 24 | 511 | 511 |
| 6 | 2019-09-25 12:52:00.0000 | WFSM | DEMOD | 90261 | 0 | 0 | 24 | 511 | 511 |
| 7 | 2019-10-01 12:10:55.0000 | 0 | NORM | 92240 | 49868192 | 0 | 24 | 511 | 511 |
| 8 | 2019-10-01 12:12:26.0000 | 0 | NANS | 92240 | 0 | 2048 | 24 | 511 | 511 |
| 9 | 2019-10-01 12:12:30.0000 | 0 | REOR1 | 92240 | 0x1FF | 1 | 25 | 511 | 511 |
| 10 | 2019-10-01 12:12:30.0000 | 0 | REOR1 | 92240 | 5 | 0 | 25 | 511 | 511 |
| 11 | 2019-10-01 12:18:26.0000 | 0 | INVER | 92240 | 1 | 0 | 6 | 511 | 511 |
| 12 | 2019-10-01 12:19:09.0000 | 0 | REOR2 | 92240 | 0x1FF | 1 | 5 | 511 | 511 |
| 13 | 2019-10-01 12:19:16.0000 | 0 | PIPE2 | 92240 | 0x7F | 0 | 5 | 511 | 511 |

Top: expected, usual results for the pipeline. Bottom: obtained final results, clearly wrong at the first look. An incorrect demodulation matrix has been used on the dataset (can happen due to planning or operator error).

UDP entries during the pipeline run. (Excerpt.) The highlighted return values are warnings for NaN-s produced in the dataset during the operation (a usual case), and for demodulation matrix mismatch due to different feed select mechanism positions (i.e. it is for the other optical path).

| References | Acknowledgments |
|---|----------------------------|
| K. Albert, J. Hirzberger, D. Busse, and et al. Autonomous on-board data processing and instrument calibration software for the SO/PHI. Proc. SPIE, 707:10707 – 10707 – 9, 2018. K. Albert, J. Hirzberger, D. Busse, and et al. Performance analysis of the SO/PHI software framework for on-board data reduction. arXiv e-prints, page arXiv:1905.08690, May 2019. S. K. Solanki, J. C. del Toro Iniesta, J. Woch, and et al. The Polarimetric and Helioseismic Imager on Solar Orbiter. arXiv e-prints, page arXiv:1903.11061, Mar 2019. | MAX-PLANCK-GESELLSCHAFT |
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